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OPERATION TUMBLER-SNAPPER

Project 1.13

MEASUREMENT OF AIR BLAST PRESSURE VS TIME

REPORT TO THE TEST DIRECTOR

by

G. W. Cook and V. E. Benjamin

March 1953

Scale Models of Today are Ships and Air Craft of Tomorrow

David Taylor Model Basin
Washington 7, D. C.

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ABSTRACT

Ground level air blast pressures were measured by the David Taylor Model Basin on the main blast line and in aircraft parking areas for Shots 2, 3, and 4. The purpose of these measurements was two-fold: (a) to provide blast pressure data at specific locations of especial interest to Program 3 in correlating damage to aircraft on the ground and (b) to provide blast pressure data suitable for a check of asimuth symmetry and for comparison with data obtained by other activities participating in the TUMBLER-SNAPPER series of tests. Eight interferometer (Buck) gages and eight David Taylor Model Basin capacitance gages were used in the operation.

Reproductions of the recorded pressure-time curves are placed in the main body of the report. In addition, peak pressure values, positive and negative phase durations, and positive and negative impulse values are tabulated for each shot.

Self-contained gage stations were used to make these measurements, i.e., recordings were made at each gage location rather than at a central recording station. This technique appears to be quite successful and requires no costly cable trenches. The development of more compact apparatus specifically designed for mounting in a small cylindrical housing underground is desirable.

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PREFACE

Early in February, 1952 the David Taylor Model Basin was asked to participate in the forthcoming TUMBLER-SNAPPER atomic weapons test operations to be conducted at the Nevada Proving Grounds. The Model Basin was requested to make measurements of air blast pressures which were to be correlated with observed damage effects to parked aircraft located at various distances from ground zero.

Preliminary planning talks were held with Project 3.1 personnel at Wright Patterson Air Force Base to determine their requirements for location of pressure gages in the aircraft parking areas. It was suggested that the Model Basin use existing interferometer (Buck) pressure gages which were on hand at the Los Alamos Scientific Laboratory. These gages had been returned from GREENHOUSE operations and their condition was unknown.

Model Basin participation was set up as Project 1.13 under Program 1 which included all blast-pressure measurements. A control station was selected on the main blast line for comparison measurements with other participating projects. With a check at this station on gage response similarity, measurements taken in areas removed from the blast line could be compared with those at corresponding distances from ground zero on the blast line.

Because of the questionable condition of the available interferometer gages, Project 1.13 proposed, in conference with Project 3.1, that a type of pressure measuring system which had been developed at the Model Basin be constructed for use in the TUMBLER operations in conjunction with as many of the Buck gages as could be rehabilitated.

At first it was agreed that the Model Basin would build five channels of the TMB capacitance gage system; this was later expanded to eight channels when the merits of this system were more widely understood and when the exact condition of the Buck gages had been determined.

The authors visited Los Alamos Scientific Laboratory on 12 February 1952 and, through the cooperation of their J-10 Division and of Kirtland Air Force Base, secured 16 Buck gages in various states of repair and completeness. Final details of the gage installation requirements were settled with Test Command, AFSWP, at Kirtland AFB during this visit.

A major construction program was started at the Model Basin and in about five weeks the capacitance gage systems were constructed and calibrated and 10 Buck gages were put in operating condition, calibrated, and fitted to steel mounting boxes. In addition, all required supporting instrumentation and supplies had been obtained. The Air Force

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provided air transportation for the 28,000 pounds of instruments and auxiliary equipment to Indian Springs Air Force Base, Nevada, in time for the Model Basin's scheduled participation in Shot 2.

ACKNOWLEDGMENTS

Due to the very short preparation time allowed Project 1.13, the task of designing, building, and calibrating test equipment could not have been accomplished without the wholehearted support of the Industrial Department and the Supply and Fiscal Department of the David Taylor Model Basin.

In addition to the authors the following Model Basin personnel participated in the field operations at the Nevada Proving Grounds:

Charles W. Hoffman
Robert G. Tuckerman
Fred B. Miller
Frank H. Kendall, Jr.
Norman E. Barron

Four Air Force men were assigned to the Project at the test site and cheerfully performed a great variety of duties in the field operations:

Sgt. Thomas H. Burke
Cpl. Thomas Elsberg
PFC Robert Fenton
PFC Winston Hebert

The cooperation received from the Test Command, the Program 1 Director, other Program Directors and Project Officers, and the supporting organizations at the Proving Grounds was very much appreciated.

CONTENTS

ILLUSTRATIONS

TABLES

CHAPTER 1

INSTRUMENTATION

1.1 INTRODUCTION

Air-blast pressure measurements were conducted by Project 1.13 during Shots 2, 3, and 4. The results fulfill two purposes: (1) they provide pressure-time information to correlate with observed damage to parked aircraft, and (2) they provide a check on azimuth symmetry by comparing blast pressure records obtained in the Project 3.1 aircraft areas with those from the main blast line.

Pressures at each gage station were recorded at ground level. In general the gages were located in open terrain but some were behind aircraft-protection revetments and one was at the bottom of an open excavation-type aircraft shelter.

Two types of pressure measuring systems were employed: (1) a capacitance gage resonant-bridge carrier system initially developed at the David Taylor Model Basin by Dr. T.A. Perls (Ref. 1) and Mr. G. W. Cook (Ref. 2), and (2) the interferometer gage more commonly known as the Buck gage after its developer Dr. W.E. Buck (Ref. 3).

1.2 THE TMB CAPACITANCE GAGE SYSTEM

The TMB capacitance gage system uses a capacitance-type pressure pickup and a resonant bridge carrier system and records by means of a moving film camera. It has excellent transient frequency resolution capabilities and is remarkably stable in the presence of shock, vibration, and sudden temperature changes. The system may be studied in two parts: (1) the pressure gage, and (2) the carrier amplifier, power supply, and camera.

1.2.1 The Pressure Gage

Figure 1.1 shows a cross section of the pressure-sensing element of the gage as mounted in a baffle plate. The 2 by 3 foot baffle plate was oriented lengthwise toward the blast with the gage centered nearer the rear portion of the plate. The sintered brass filter (Porex*) provides mechanical and thermal protection to the gage

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*Porex Grade 2. Manufactured by Moraine Products Division, GMC, Dayton, Ohio.

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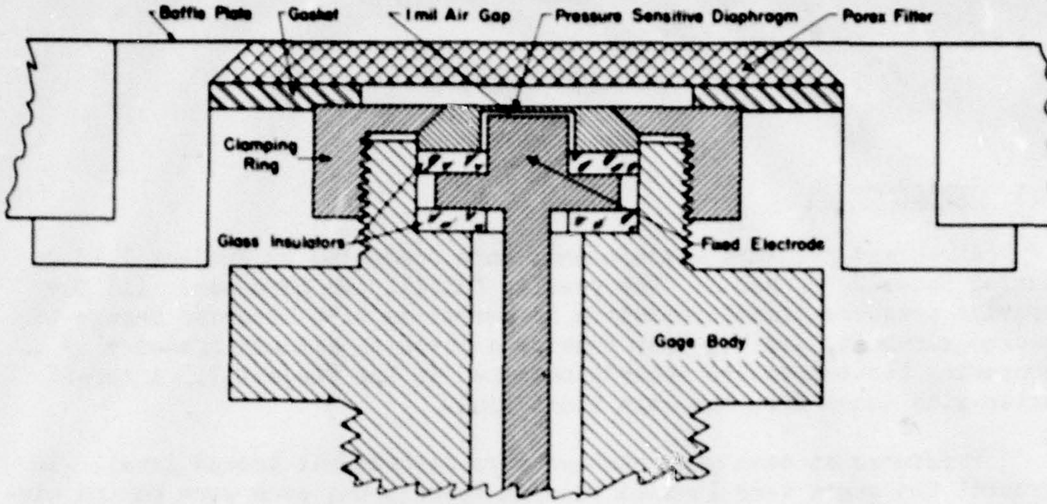

Figure 1.1 Section of Gage Head

The gage head consists essentially of a central fixed electrode and a pressure sensitive diaphragm closely spaced to the fixed electrode so as to form an electrical capacitance.

diaphragm. The filter was waterproofed by dipping in a solution of silicone oil in methyl ethyl keytone and then baking dry. It was felt that wax, which had been used in the past with Porex filters in Buck gages, might not be a satisfactory agent to use for waterproofing since the initial high thermal flux from nuclear explosions could melt the wax residue in the filter and clog the very small pores before the arrival of the shock wave. The design of the gage itself was based in part on the requirement of minimizing the influence of temperature changes, and, in this respect, the use of Kovar and glass construction was of benefit. A photograph of the pressure gage is shown in Figure 1.2. Circuitry within the gage consists of a four-arm capacitance bridge with the diaphragm and fixed-electrode combination of the pressure-sensing element as the active bridge arm (Figure 1.3). Trimming capacitors and driver and pickup transformers are mounted within the heavy-walled box of the gage body. The driver transformer is tuned to resonance with the bridge capacitance as seen from the driving points, a-b, and the pickup transformer is tuned to resonance with the bridge capacitance as seen from the pickup points, c-d.

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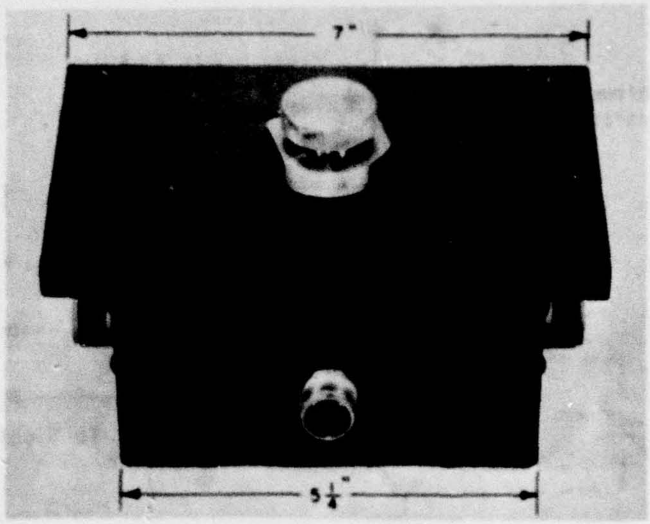

Figure 1.2 Pressure Gage

The gage head is an integral part of the heavy metal bridge box. The central circular part is the diaphragm cup which is held in place by the knurled clamping ring.

After the bridge is tuned, the entire circuit is imbedded in NEL casting resin. After imbedding, the gage circuit is impervious to shock excitation and to weather conditions, and the passive elements of the bridge are insulated from sudden temperature changes. Long-term unbalances resulting from temperature changes are compensated for by automatic balancing features in the carrier amplifier unit. Because of the resonance conditions in the bridge, very large signal voltages are produced by very small capacitance changes.

1.2.2 <u>Carrier Amplifier, Power Supply, and Camera</u>

A typical field installation of the capacity gage system is shown in Figure 1.4. The gage is attached to a heavy steel baffle plate which in turn is bolted to a steel drum secured to the wood structure of the underground instrument pit. A flanged pipe further supports the assembly and provides a passageway for the gage cables. The carrier amplifier, power supply, and camera are mounted in the lower portion of the instrument pit in a shock-mounted rack. Timbers support a removable plywood platform above the instruments so that after all adjustments have been made, the top portion of the pit can be filled with sandbags

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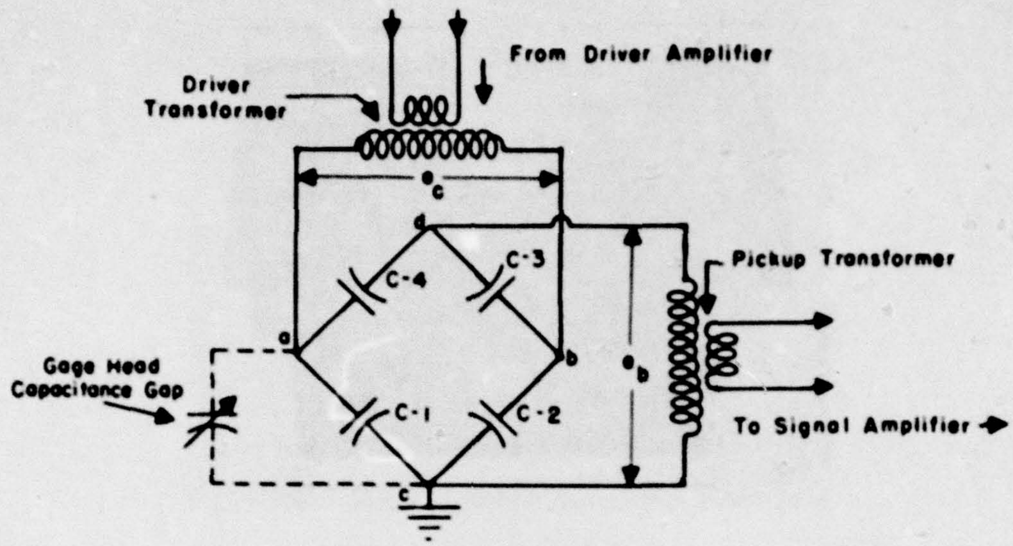

Figure 1.3 Capacitance Gage Circuit

to the level of the ground to provide blast and radiation protection for the electronic equipment and the camera. Certain wires are brought to ground level for final arming of the equipment after final pre-shot dry runs. In the interest of brevity, only a short functional description of this measurement system is given here.

A special bridge circuit, similar to that shown in Figure 1.3 is energized by a carrier current of 500 kc by means of a low impedance transmission line. The frequency of this carrier current is crystal stabilized. The bridge circuit is balanced before recording. The electrical capacity of the air gap in the gage is a part of the total capacity in one leg of the bridge circuit. Pressure applied to the gage head changes the capacity of the gap.

Initial balancing of the system is accomplished by adjustment of controls on the carrier amplifier unit. Thereafter any unbalanced voltage from the bridge is transmitted back to the carrier amplifier via another transmission line. This voltage is amplified and fed into a special phase-amplitude sensitive discriminator circuit in which the signal voltage is compared with the bridge driving voltage. The sense of the bridge unbalance, i.e., whether the unbalance represents positive or negative pressure applied to the outer surface of the diaphragm, is determined by means of phase comparison. At the same time the amplitude of the signal voltage is determined, the r-f component

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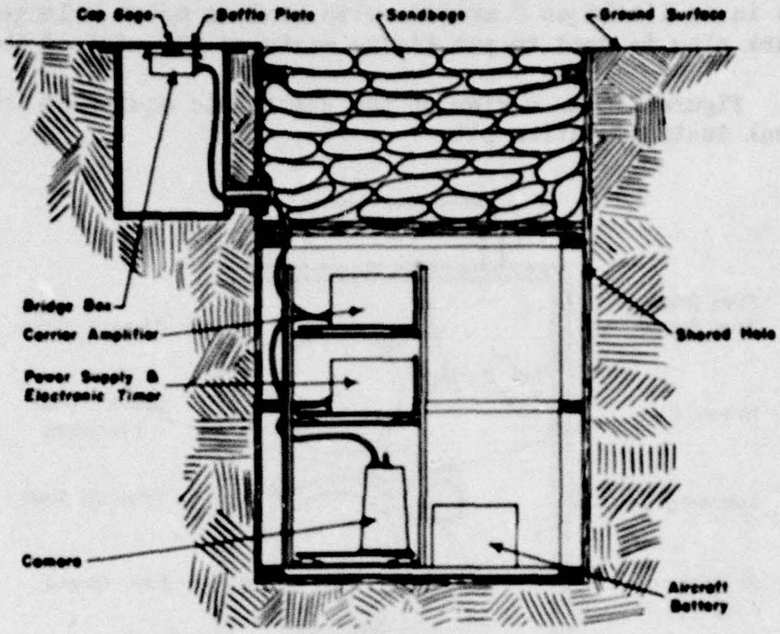

Figure 1.4 Typical Capacitance Gage System Installation

The rectangular hole is about 6 feet deep. A double plywood platform supports the sandbags which provide blast protection for the electronic instruments. The camera is placed at the bottom of the pit where maximum distance of interposed earth provides radiation shielding.

is removed by rectification, and the resulting d-c signal represents the sense and magnitude of the pressure. This d-c signal is used to deflect the electron beam of a cathode-ray tube in the camera unit. The camera records the position of the cathode-ray beam on a moving film. A special timing oscillator and spark discharge electrode places a time base on the film.

Primary power is furnished for the system by a 24 volt aircraft-type storage battery. A dynamotor provides plate voltage through electronic voltage regulators.

The mechanism of the recording camera is shown in Figure 1.5. A cathode-ray tube is mounted on the far side of the camera and the spot of light from the tube face is projected by two mirrors and focused by a lens on the 16 mm film. The takeup reel is driven by a d-c motor. One hundred feet of Linagraph Ortho film can be run through

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the camera in as little as 2 seconds with maximum motor voltage. A miniature spark plug is used to put timing marks on the edge of the film.

Figure 1.6 is a view of the electronic equipment installed in a typical instrumentation pit.

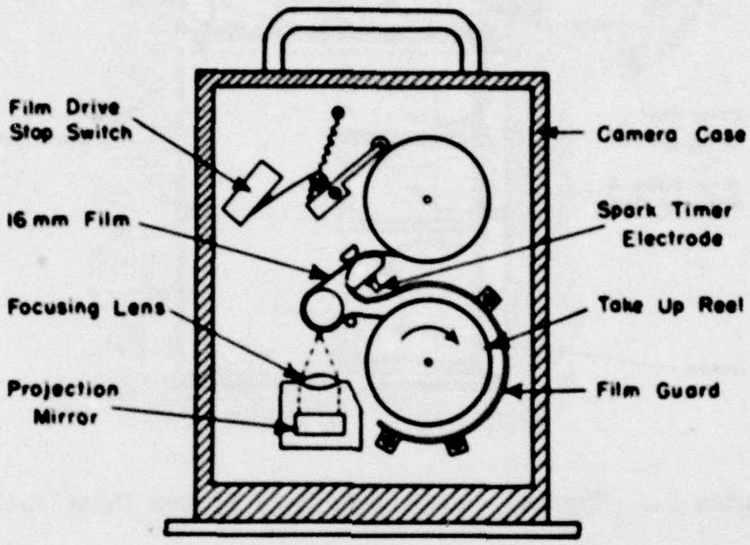

Figure 1.5 Recording Camera for Capacitance Gage System

Mirrors project the spot of light from the cathode-ray tube, mounted on the reverse side of the camera, to the moving film.

Figure 1.6 Capacitance Gage Instrumentation Pit

1.3 THE BUCK GAGE

The interferometer or Buck gage is well described in the literature (Ref. 3). It is a self-contained unit that photographically observes interference fringes formed between an optically flat pressure sensing diaphragm and a slightly concave glass backing plate. The Buck gage was originally developed for pressure measurements in high explosive work. Its adaptation to nuclear weapons tests introduces several problems:

1. In areas of high nuclear radiation intensity, the recording film must be protected from this radiation.

2. When radiation shielding is employed, the pressure diaphragm can no longer be flush with a baffle surface.

3. In the areas where nuclear radiation protection is needed, pressures are usually high and a higher natural frequency diaphragm could be used. The frequency attenuation introduced by the required lead tube nullifies the good frequency characteristics of such diaphragms.

4. With the longer periods of sustained positive and negative pressures characteristic of atomic explosions, the 100 feet of film runs through too fast to record the entire phenomena. In order to maintain any time resolution as far as readability of records is concerned, the film velocity would have to be maintained and a much longer film would be required.

1.3.1 Buck Gage Installation

Figure 1.7 shows a typical Buck gage installation. Machined interlocking lead bricks were stacked all around the gage box for nuclear radiation shielding. The pressure tube consisted of a 1/4 inch diameter hole in the center of a lead filled pipe. Fine lead shot was poured around the tube to fill any gaps in the brick. The large battery box was needed to house the dry cells required for d-c operation of the gage.

Figure 1.8 is a photograph of a simpler installation of a Buck gage in an area where radiation protection was unnecessary. The Buck gage has been affixed to the baffle plate from which it is to be suspended, and the cables for timing and power are being connected before the baffle plate cover is lowered in place. Caulking compound is spread on the top flange of the box to provide a waterproof seal. The Buck gage is shown installed in the gage box in Figure 1.9. The face plate of the gage, with the Porex filter over the diaphragm, is mounted flush with the baffle plate. After the baffle plate is fastened to the box, the ground surface is faired level with the surrounding terrain.

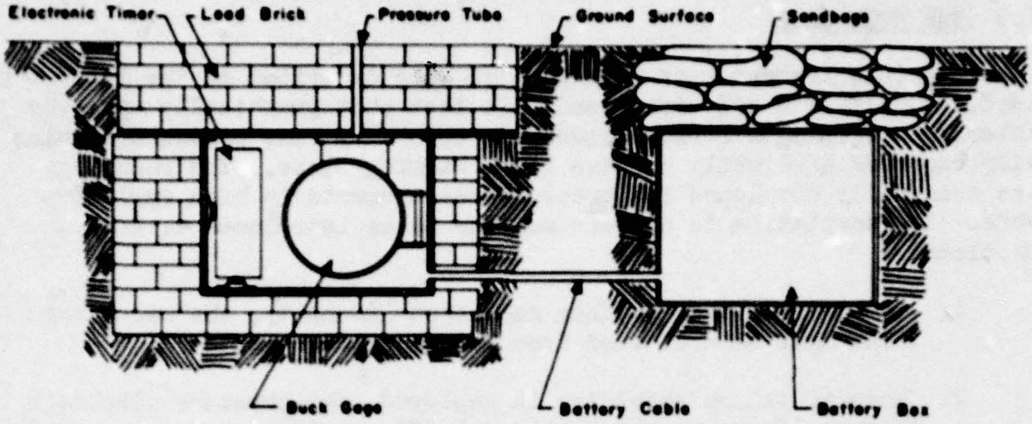

Figure 1.7 Buck Gage Installation with Lead Shielding

The Buck gage is suspended from the heavy steel cover plate. Machined interlocking lead brick provide radiation shielding. Pressure is transmitted to the gage diaphragm through the pressure tube.

Figure 1.8 Buck Gage Attached to Baffle Plate

Figure 1.9 Buck Gage Installation

1.4 ACTIVATING CIRCUITS

Thus far the two gage systems have been described as separate units. The activating circuits which turn power on, start cameras, and move sequencing cams operate in a similar manner for both circuits and will now be considered.

Certain "last close" wires were brought to the top of the ground at each gage location so that the equipment could be put in the "ready" condition after the last dry run prior to a shot. After that, the automatic features described below functioned at the proper times so that the cameras would record the transient pressure phenomena for each shot.

1.4.1 Power on Signals

Relay signals turned the primary power on for all gages at minus 30 minutes for the capacitance gages and at minus 5 minutes for the Buck gages. As stated before, each system operated from its own battery power source.

1.4.2 Camera Starting Devices

Since insufficient film was available in the cameras to record from the instant of detonation T_o to the end of the pressure wave, it was necessary either to provide a time delay after a T_o signal or to start the cameras a known time before the arrival of the shock wave at any particular gage station. As other projects were gathering sufficient data on time-of-arrival of the blast wave with respect to the instant of detonation, all Project 1.13 records express zero time t_o as the arrival time of the initial shock front at each gage.

For the gages closest to ground zero, the cameras were initiated from a "blue box" circuit and a mechanical time delay (see Appendix A—Thermal Shield Remover). All other recording stations obtained camera-start signals from blast-actuated switches placed about 800 feet ahead of the gage toward ground zero so that the cameras started about 0.7 seconds before the arrival of the shock front. This allowed sufficient time for a calibration step to be recorded and for the film to get up to speed.

Figure 1.10 shows the blast actuated trigger arrangement. Two units were employed at each station with the two aluminum break foils connected electrically in series. The function of the foil circuit was to hold a relay open until either or both foils broke as a result of the impinging shock front. The foils were slotted in the center to provide a weakened point for the start of the break but were strong enough to withstand steady pressures from wind velocities of 60 to 70 miles per hour. Screens were placed over the ends of the tubes

to prevent birds or animals from breaking the foils. It should be noted that the particular advantage of a normally shorted line for a trigger system is that electromagnetic radiations present at the instant of bomb burst cannot trigger the circuit by inducing voltages across the transmission line to prematurely close a relay.

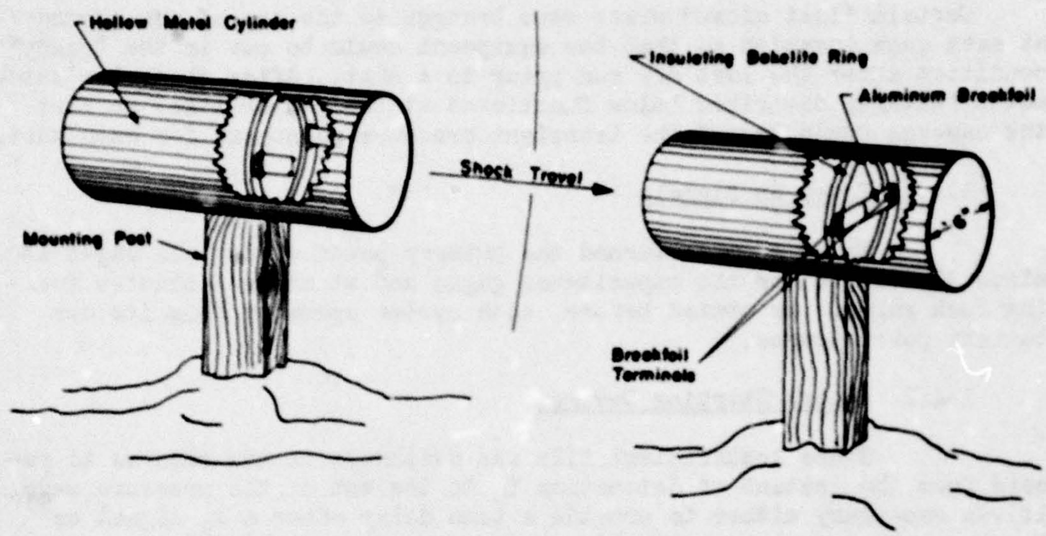

Figure 1.10 Blast Actuated Switches

The cylindrical tubes are oriented in the direction of the expected shock wave. The shock front is depicted as having just broken the foil in the first cylinder and is approaching the second switch. The two foils are normally connected in series electrically so that if either (or both) break, the switch is actuated.

1.4.3 Sequencing Functions

Subsequent to the minus 30 minute "power on" signal, the breaking of the blast actuated trigger circuit starts the following sequences for the capacitance gage circuits.

1. Film and cam drive motors start.
2. Cathode-ray beam is turned on.
3. Film-timing marker is turned on.
4. Automatic balance is turned off.
5. Calibration relay is closed.

The motor-driven cam then performs the following functions:

6. Calibration relay opens after 0.3 second.
7. Film drive motor is de-energized after 15 seconds.
8. "All Stop" cam cuts all power until apparatus may be manually reactivated.

The blast wave pressure is recorded following step 6. It is to be noted that the film drive motor is normally cut off by the "end-of-film" microswitch so that step 7 is a safety feature.

The Buck gage lamps, power, and timing circuits are turned on simultaneously with the minus 5 minute relay closing; then the sequence initiated by the break in the blast foils is as follows:

1. The film drive motor starts.
2. The cam motor starts.
3. The film drive motor is stopped by a microswitch actuated by the passage of the end of the exposed film.
4. The cam motor runs for about 20 seconds and then turns the lamp, the power, and the timer circuits off and removes voltage from the already de-energized film drive motor.

1.5 CALIBRATION OF GAGE SYSTEMS

Careful calibrations were made of the capacitance gages and Buck gages at the Model Basin before the equipment was shipped to the Nevada Proving Grounds. The calibration of the capacitance gages was rechecked after the equipment was returned from the TUMBLER-SNAPPER operations. Calibration of all gages except one agreed within 2 per cent of the original calibrated values. The original calibration value was used for analysis of all records. The Buck gages were transferred to AFSWP custody at the test site, and, therefore, recalibrations were not obtained.

Both static and dynamic calibrations were made to determine the sensitivity, frequency response, and damping for each unit. Buck gages were calibrated in the back pressure chamber of a 3 inch shock tube. A static positive pressure was built up, the Buck gage camera was started, and the shock-tube diaphragm was punctured to suddenly reduce the pressure to atmospheric conditions. A calibrated Statham pressure gage was used to read initial overpressure, and the photographic record was analysed to determine the number of fringe changes per pounds per square inch and to observe the damping and frequency responses of the gage.

Capacitance gages were calibrated statically for sensitivity and with a steep fronted shock wave passing across the diaphragm for

transient characteristics. Unlike the Buck gage which has only one full-scale value, the capacitance gage system can be calibrated for full-scale detector deflection for each of the attenuator positions in the carrier amplifier unit.

A static calibration was obtained by applying pressure to a capacitance gage diaphragm until the amplitude of the electrical calibration step was matched. Since the electrical calibration was photographed on each pressure record, accurate static calibration can be considered to have been made at shot time. Accuracy of the electrical calibration is assured by careful selection of stable capacitors and resistors in the calibration and attenuator circuits of the system. Influences of any changes in oscillator or amplifier operating conditions are thereby nullified.

1.5.1 Frequency Resolution of Gage Systems

The frequency resolution capabilities of the capacitance gage system were determined by shock-tube experiments. Tests were made with and without the Porex filter in front of the gage diaphragm. Figure 1.11 shows the pressure responses obtained. Even though the diaphragm of the capacitance gage was virtually undamped and can be excited

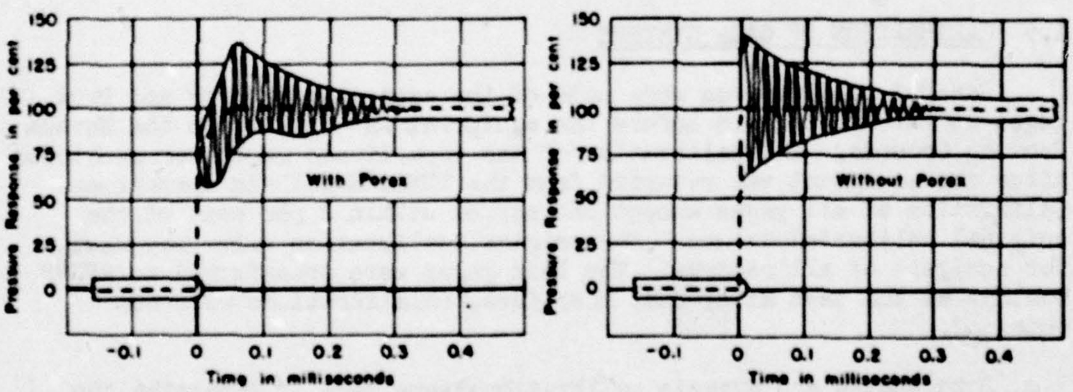

Figure 1.11 Pressure Attenuation by Porex Filter

The records were obtained from tests of a capacitance gage in a shock tube with the gage face perpendicular to the shock front. The 60 kc natural frequency of the gage diaphragm is excited because of the abruptness of the shock front. Mean values of the photographic traces are shown by dashed lines. The initial attenuation in pressure amplitude due to the presence of the Porex is 30 per cent. Attenuation decreases to zero in 60 microseconds.

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at its natural frequency of 60 kc by a sufficiently steep wave front, the mean value of the amplitude of the initial blast front can be determined accurately down to the time limitations of film speed or shock front transit time across the surface of the diaphragm.

Porex attenuation of the amplitude of an initial shock front needs to be considered only for the first 60 microseconds of a record and then only for records where the shock wave steepness is greater than about an equivalent 5000 cycles per second. Porex attenuation in the Buck gage is a minor factor since the sensitive glass diaphragms had natural frequencies of the order of a few thousand cycles per second and the exact damping factor achieved was a matter of chance and subject to change in use.

In addition the devious paths that the pressure wave must take to get down a lead tube and around a damper plug to the diaphragm introduces wave distortions far in excess of any attenuation caused by the Porex filter. The frequency response obtained with most of the Buck gages was not high.

1.6 LOCATION OF GAGES IN T-7 AREA

A map of the field locations of the 16 stations instrumented by Project 1.13 is given in Figure 1.12. All ranges shown are ground distances in feet from target zero to the survey working point in the gage area. Actual calculated ground and slant range for each gage location are given in Chapter 2 along with tables summarizing pressure data.

Gage nomenclature is based on a letter A, B, C, or D, relating to the aircraft parking areas "Able," "Baker," "Charlie," and "Dog," a number for the particular gage in the area, and a suffix "BK" for the Buck gages and "CAP" for the capacitance gages. In general the numbering sequence reads from left to right as observed from behind the gage area looking toward ground zero. The capacitance gage station on the main blast line is labeled 7-204-CAP in accordance with the regular blast line identification system.

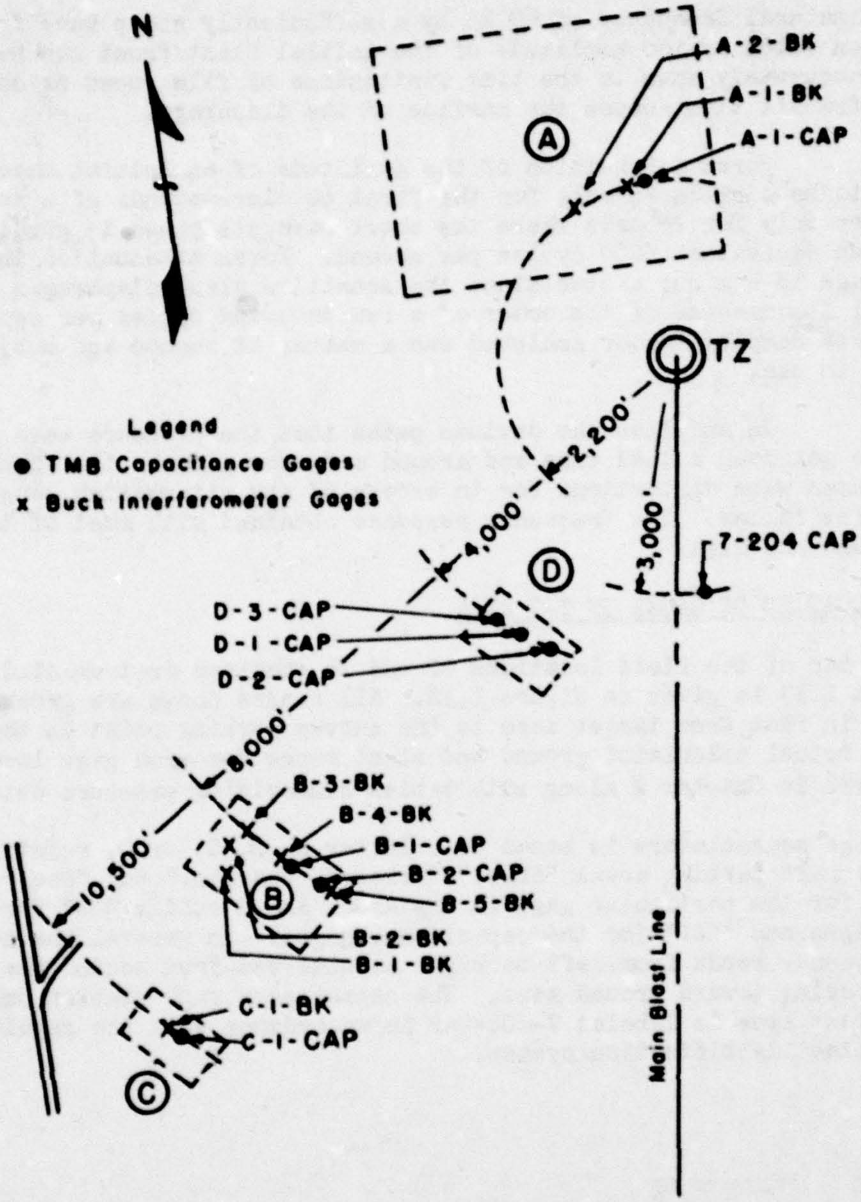

Figure 1.12 Map of Gage Locations Area T-7

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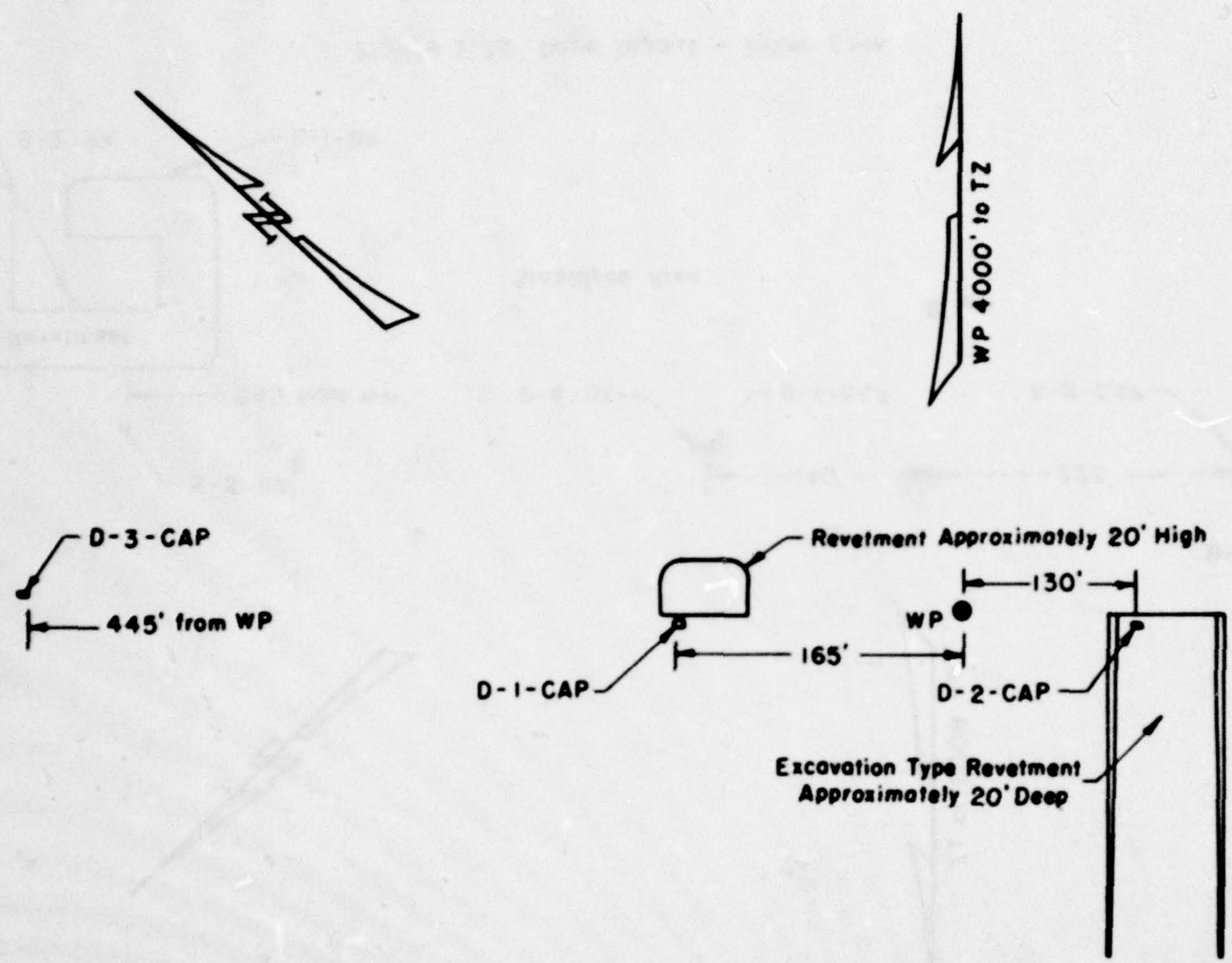

Figure 1.13 Gage Layout - Dog Area

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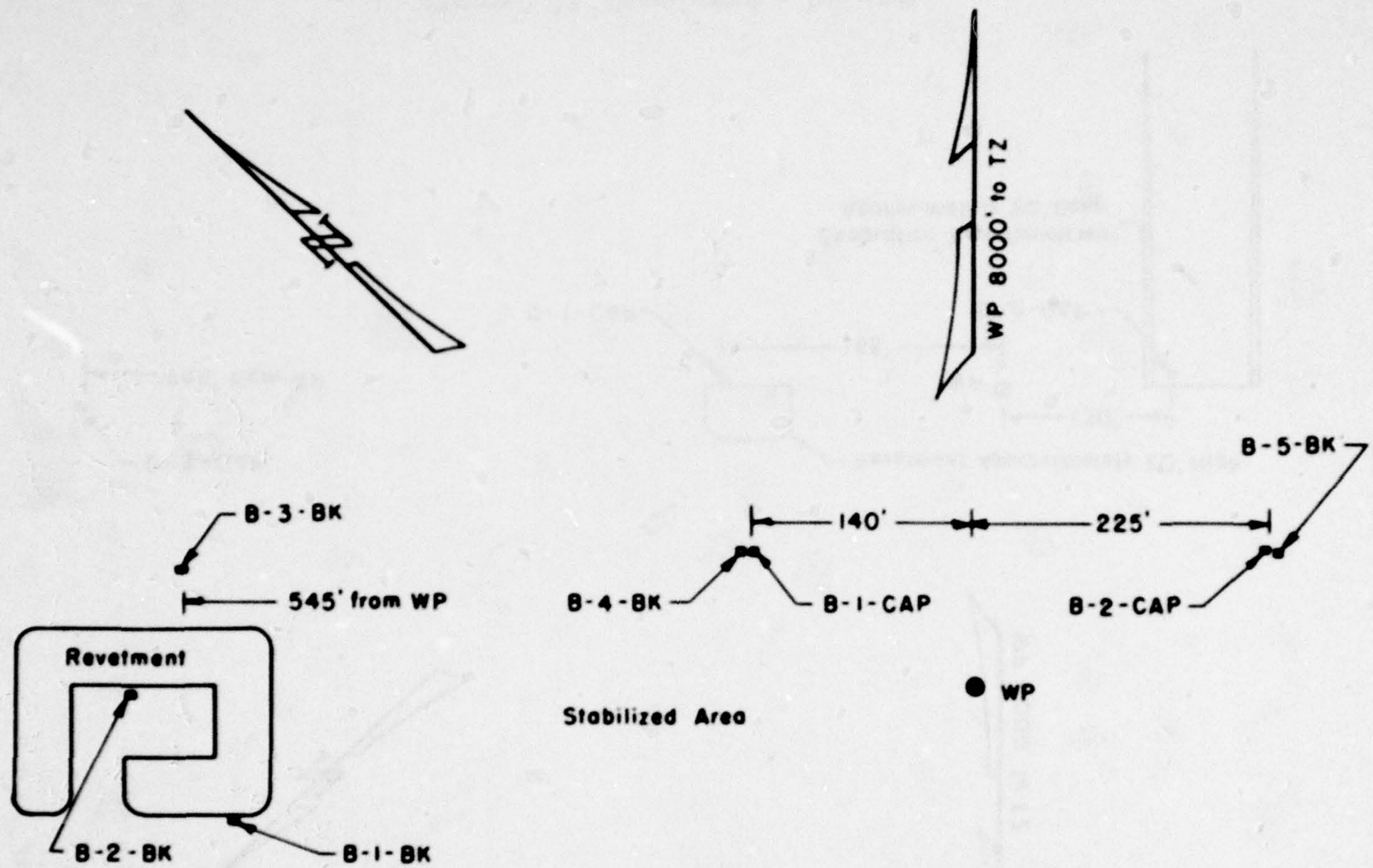

Figure 1.14 Gage Layout - Baker Area

CHAPTER 2

MEASUREMENT OF PRESSURE VS TIME

2.1 INTRODUCTION

Records of air blast pressure measurements for Shots 2, 3, and 4 for the stations mapped in Figure 1.12 are presented in this chapter. The records are grouped by shot number and presented in order of increasing ground ranges.

The record from each gage location is presented in two curves. Part (a), on left hand pages, gives the shock front shape and rise time for the first 20 milliseconds (msec) after t_o, and part (b), on right hand pages, gives the full history of the positive and negative phases of each record. Amplitude scales are the same for corresponding pages, and all time scales are based on t_o as the time of the initial pressure rise at a gage location.

Several of the Buck gages ran out of film before the pressure wave had passed. It was not possible to adjust the film drive motor to slower operating speeds and have the speed governor function properly. It would have been desirable to have all gages run at least 10 seconds after t_o so that final zeros could always be verified.

2.2 ANALYSIS OF RECORDS

The analysis of the records obtained by Project 1.13 was made with particular emphasis on instrumentation, rise time of pressure shock fronts, and notation of initial spikes and unusual waveform. Peak positive pressures, maximum negative pressures, duration of positive and negative phases, and positive and negative impulses were also studied.

The correlation of damage to aircraft with observed pressures and the comparison with previous operational test results was not the responsibility of Project 1.13.

2.2.1 Methods of Analyzing Records

The 16 mm film from the capacitance gages was analyzed with the aid of a Recordak film reader, Model MPE. The magnified projection of the record was traced to obtain a true reproduction of the wave shapes for the initial 20 msec and point by point amplitude readings were taken for the remainder of the record. Amplitudes were read directly in pounds per square inch with a Gerber variable scale.* Since a

*The Gerber Scientific Instrument Co., Hartford, Conn.

calibration step appeared on each record, the variable scale could be adjusted to read directly in calibrated pounds per square inch.

The Buck-gage records were transcribed by the process of counting fringe changes (and estimating fractional fringe changes) as a function of time and then multiplying by the calibration factor in pounds per square inch per fringe change to get the pressure.

2.3 SHOT 2 RESULTS

Figure 2.1a shows the waveforms of the initial shock fronts for Shot 2 at various distances from ground zero. The incident shock front for free air conditions was undoubtedly steep and abrupt. Some of the variations in the recorded shape of the wavefronts obtained by ground level capacitance gages are believed due to localized terrain conditions, such as the presence of objects ahead of the gage. Slight apparent negative pressures were detected ahead of the shock front at 7-204-CAP and B-2-CAP. The capacitance gage systems in themselves are insensitive to relatively large displacement-acceleration effects.

The reasons for the formation of precursor phenomena in general is not known to the authors at this time, but the possible influence of objects ahead of the gages can be observed. For 7-204-CAP on Shot 2, there was a rough low mound of earth about 40 feet in advance of the gage and, in addition, an anchor beam for a tower guy cable protruded about 1 foot above the ground 20 feet ahead of the gage. The sudden dip in the record with a minimum at 0.5 msec may result from the turbulence set up by these objects. Both D-1-CAP, which was located at ground level but close behind a high wall-type revetment, and D-2-CAP, which was at the bottom of an excavation-type revetment and immediately behind the end wall, show the initial pressure fronts starting to rise, then taking time to "fill-in" behind the wall and in the excavation void.

The B-1-CAP gage was in a stabilized area with a clear space several hundred feet in front. The pressure record is clean and the wave front is abrupt. The B-2-CAP gage was in the same area but a concrete camera pedestal stood about 80 feet in front. It appears logical to assume that the disturbance to the wave front was caused by this pedestal.

Figure 2.1b gives the full time history of the pressure waves and Table 2.1 summarizes data for Shot 2.

2.4 SHOT 3 RESULTS

Pressure-time curves from the Able area are given in Figures 2.2a and 2.2b. There is much similarity of wave form between the two

TABLE 2.1

Ground Level Pressure Data - Shot 2

Gage Station	Ground Range feet	Slant Range feet	Peak Positive Pressure psi	Positive Phase Duration sec	Positive Impulse psi-sec	Maximum Negative Pressure psi	Negative Phase Duration sec	Negative Impulse psi-sec
7-204-CAP	2880	3080	3.74	0.39	0.48	0.60	0.90	0.28
D-1-CAP	3920	4070	2.26	0.36	0.28	0.54	0.96	0.30
D-2-CAP	3930	4090	2.27	0.35	0.24	0.60	0.95	0.39
B-1-CAP	7890	7970	0.96	0.43	0.15	0.25	0.88	0.18
B-2-CAP	7890	7970	1.39	0.35[a]	0.11	0.33	1.19	0.18

(a) Timing erratic for this gage.

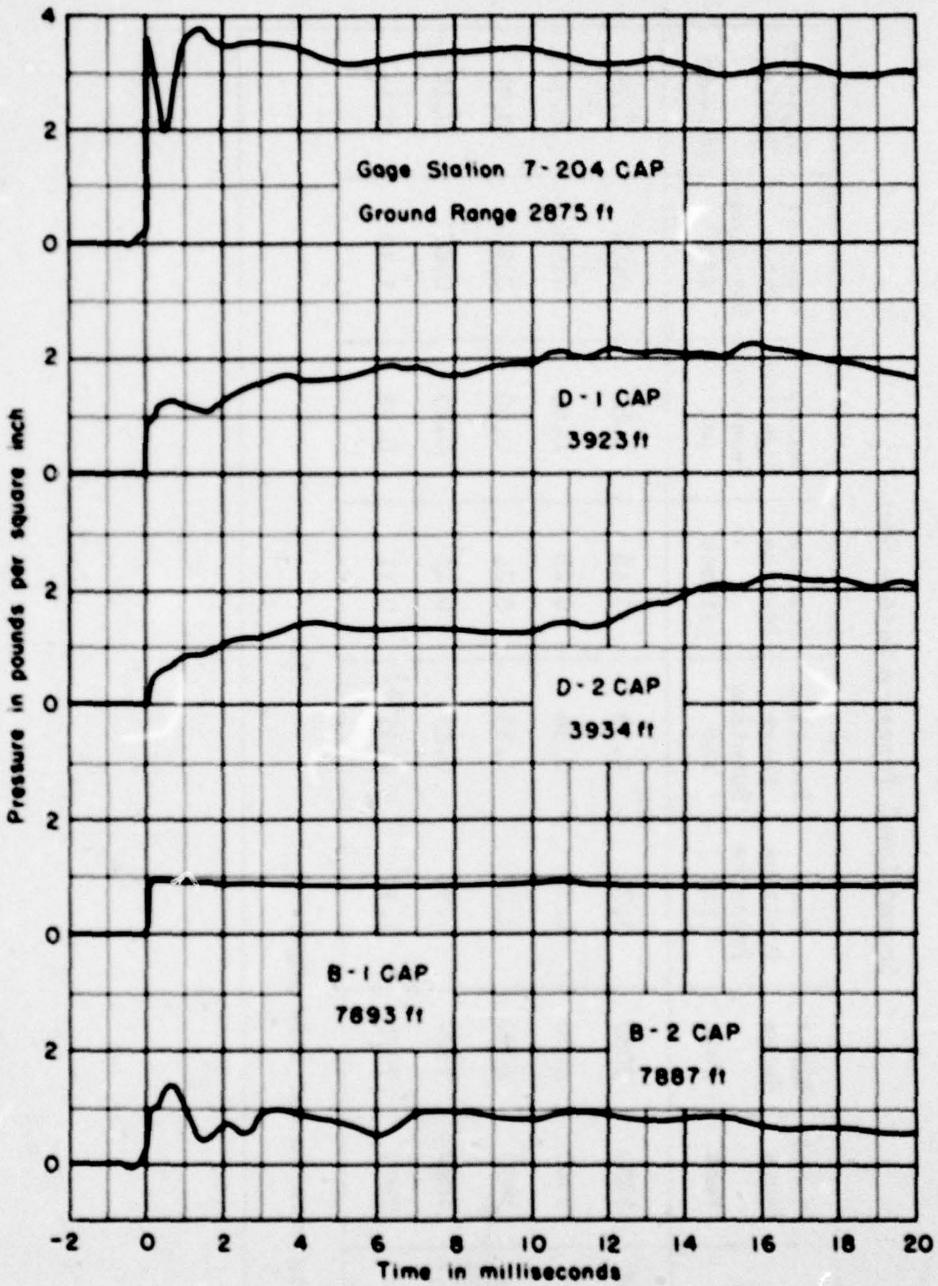

Figure 2.1a - Shot 2. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

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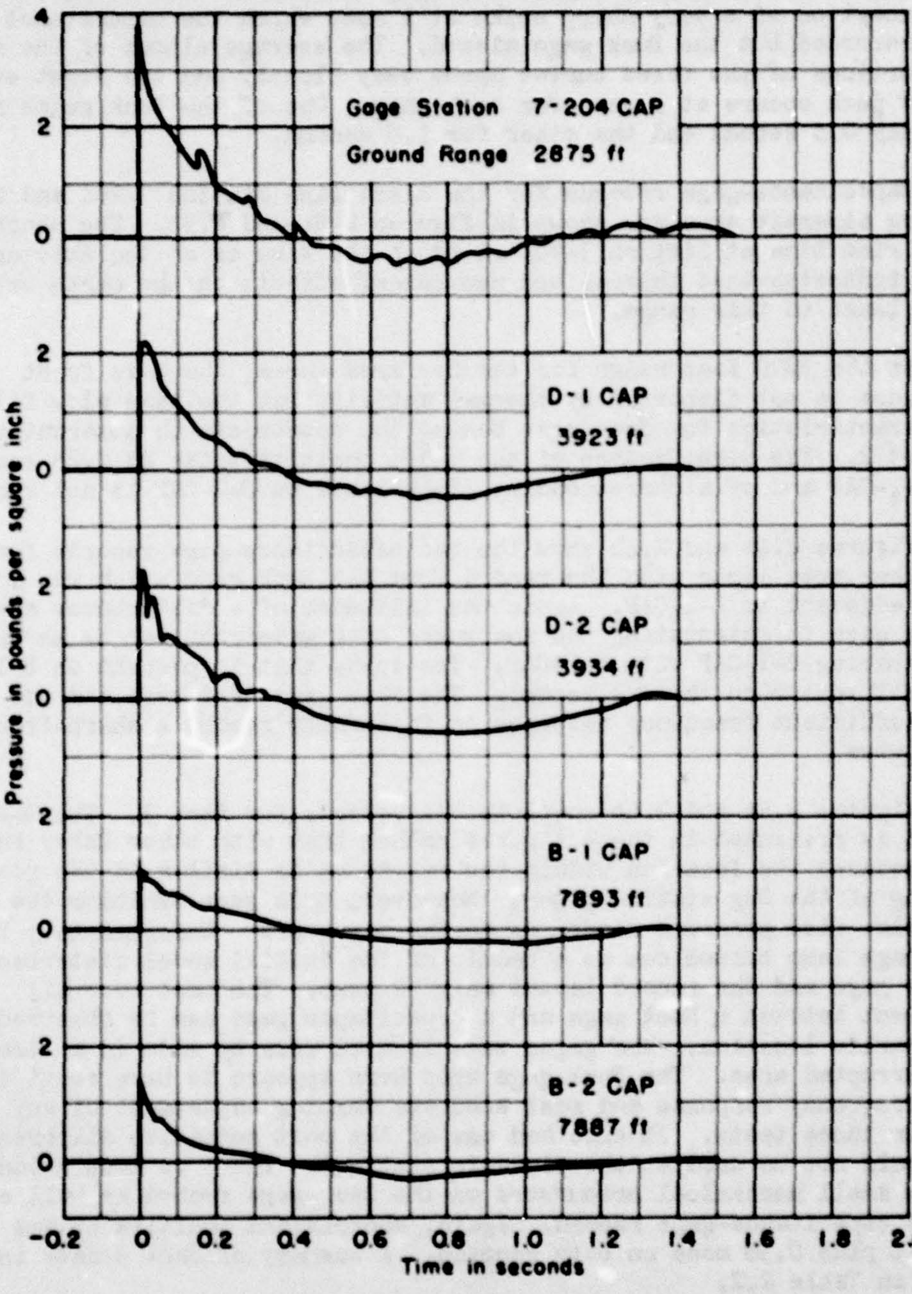

Figure 2.1b - Shot 2. Air Blast Pressure at Ground Level versus Time. Full Time History

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Buck-gage records and the capacitance-gage record at this station with the exception of a very sharp spike at 1 msec which the capacitance gage recorded but the Buck gage missed. The average slopes of the rising portions of the three curves agree very closely and the first sustained peak occurs at 3 msec for each gage. One of the Buck gages ran for only 0.5 second and the other for 1.8 second.

Capacitance-gage records for the blast line Station 7-204 and in the Dog aircraft area are shown in Figures 2.3a and 2.3b. The shock front rise time at Station 7-204 is about the same as at the Able area which indicates that thermal and mechanical effects on the earth extended at least to this range.

At the 3870 foot range for the Dog area gages, the wave front steepness is not distorted by thermal activity but the same slow fill-in characteristics for pressures behind the revetments is apparent as in Shot 2. The significance of the sharp positive spike at 0.25 second for D-1-CAP and of a corresponding disturbance on D-2-CAP is not known.

Figures 2.4a and 2.4b show the two capacitance-gage records for the Baker area along with the record from the Buck gage which was located adjacent to B-2-CAP. Again the influence of a disturbance ahead of the gage in attenuating the sharpness of a wavefront can be shown by comparing B-1-CAP with B-2-CAP. The spike that is present on B-1 does not appear on the B-2 record. The Buck gage used here did not have sufficient frequency response to faithfully record a sharp-fronted shock wave.

Figures 2.5a and 2.5b complete the records for Shot 3. The B-2-BK record is presented in these figures rather than with other Baker records because its location within the revetment is similar to the positioning of the Dog station gages. Moreover, this gage exhibits the same slow rise pressure record as do the Dog gages. Unfortunately the Buck-gage lamp burned out as a result of the initial shock disturbance to the gage and the record lasted only 50 msec. The best over-all agreement between a Buck gage and a capacitance gage can be observed at the Charlie location. The gages were located side by side in a clear uninterrupted area. The Buck gage used here appears to have about the best frequency response and most accurate damping adjustment of any used in these tests. It also had one of the most sensitive diaphragms and could not be used at the close-in stations. There is even evidence of the small mechanical precursors on the Buck-gage record as well as on the capacitance-gage record. Again, unexplained positive spikes show at plus 0.38 msec on both records. A summary of Shot 3 data is given in Table 2.2.

[redacted]

TABLE 2.2

Ground Level Pressure Data - Shot 3

Gage Station	Ground Range feet	Slant Range feet	Peak Positive Pressure psi	Positive Phase Duration sec	Positive Impulse psi-sec	Maximum Negative Pressure psi	Negative Phase Duration sec	Negative Impulse psi-sec
A-1-BK	2180	4080	15.0	0.54	2.13	(b)	(b)	(b)
A-2-BK	2180	4080	8.69	0.82	2.61	2.01	(b)	(b)
A-1-CAP	2180	4080	12.3(a)	0.88	3.13	2.4	1.98	3.6
7-204-CAP	2900	4510	7.9	0.86	2.67	1.46	2.36	2.11
D-1-CAP	3870	5180	6.9	0.88	2.08	1.38	2.14	2.29
D-2-CAP	3870	5180	7.2	0.95	2.02	1.7	2.80	2.14
B-1-CAP	7780	8500	6.2(c)	0.73	0.82	1.26	2.92	2.42
B-2-CAP	7790	8510	4.54	0.90	1.00	0.66	1.85	0.79
B-5-BK	7790	8510	4.00	0.89	0.80	0.71	(b)	(b)
B-2-BK	7900	8620	3.18	(b)	(b)	(b)	(b)	(b)
C-1-BK	10250	10800	3.03	1.27	1.12(d)	0.43	(b)	(b)
C-1-CAP	10250	10800	2.8	1.06	0.96(d)	0.66	(b)	(b)

(a) Initial spike of 19.9 psi - see Table 2.4.
(b) End of film.
(c) Initial spike of 7.9 psi - see Table 2.4.
(d) Considered too high.

[redacted] [redacted]

[redacted]

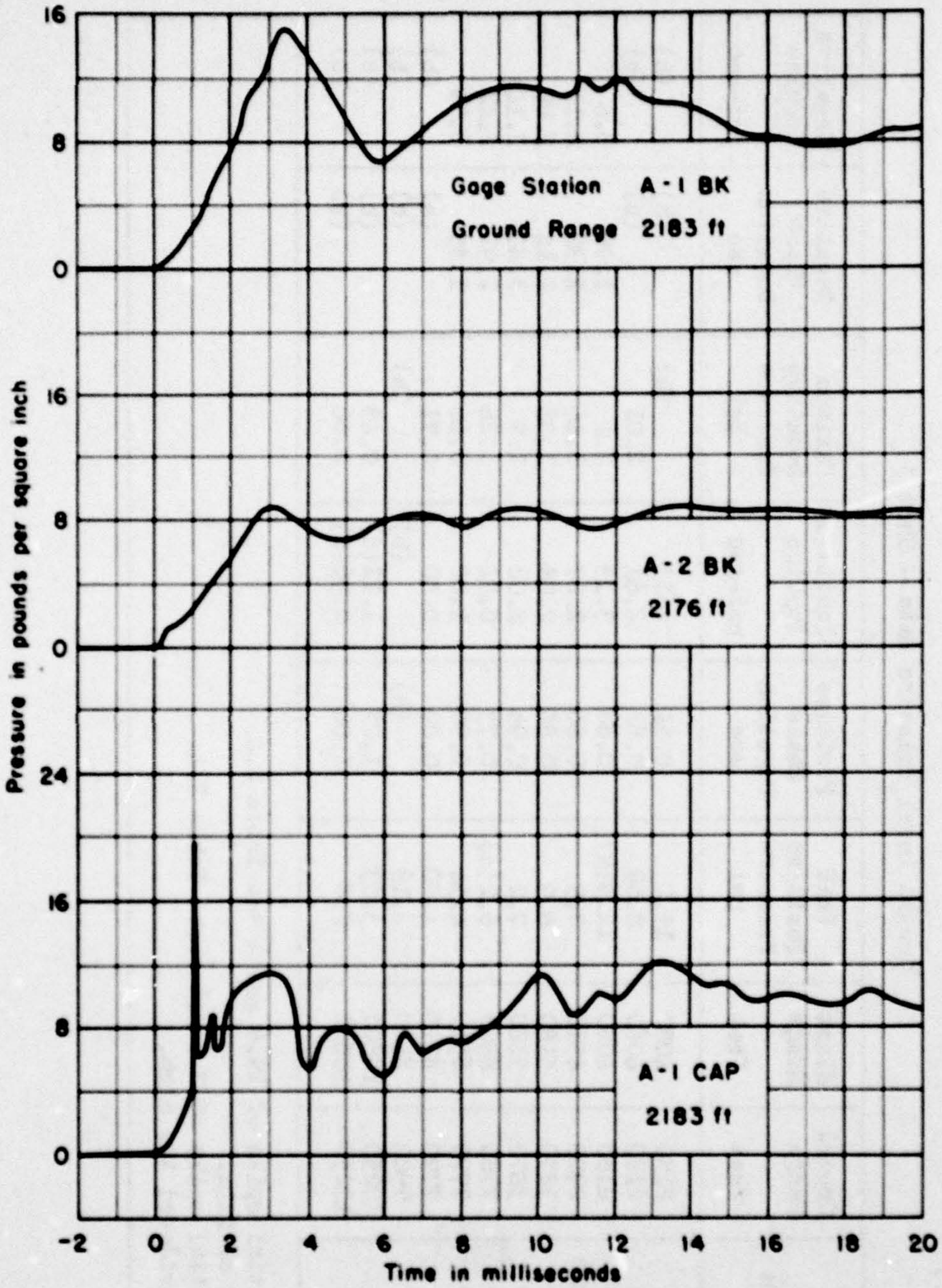

Figure 2.2a - Shot 3. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

[redacted]

[redacted]

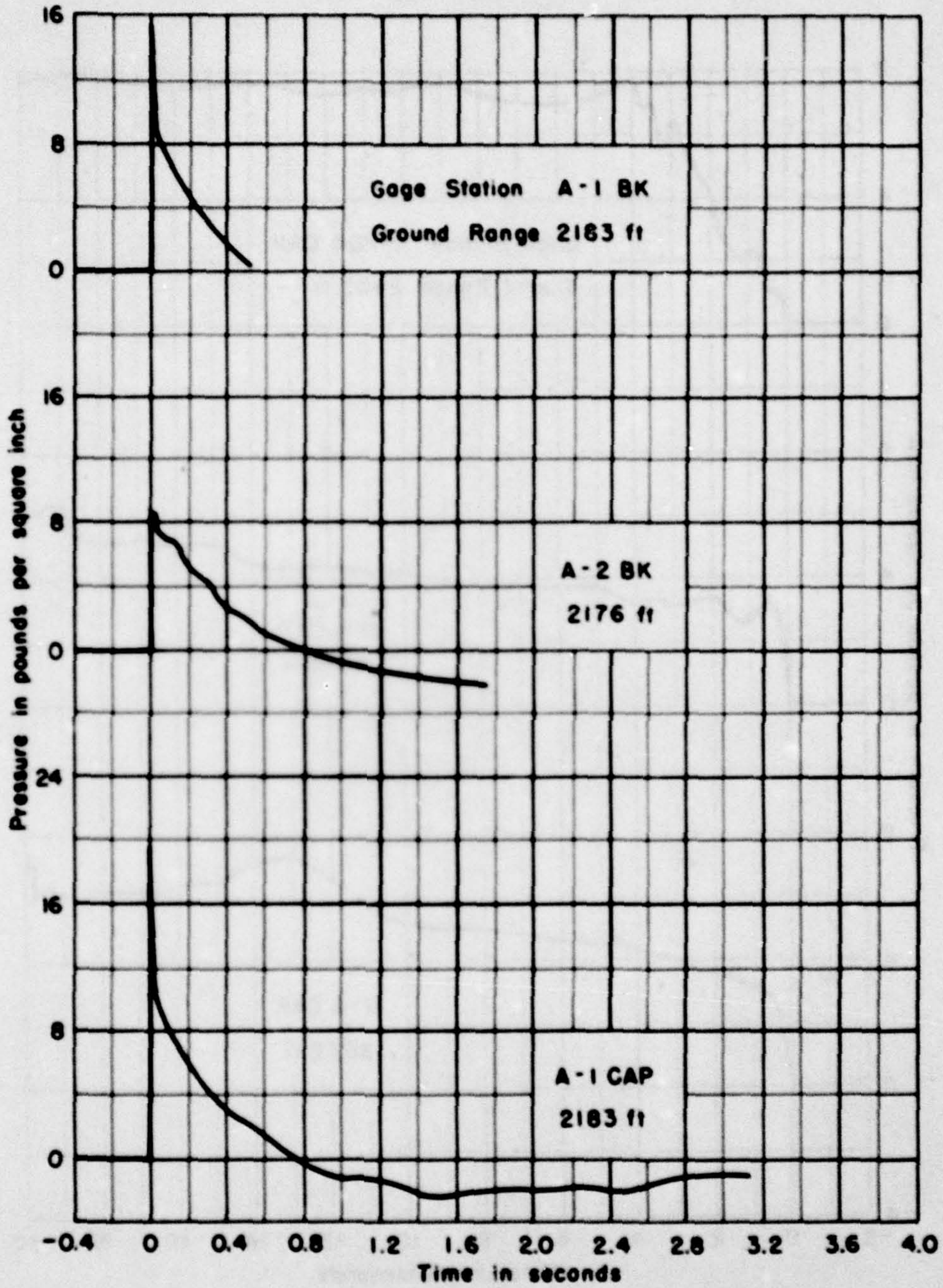

Figure 2.2b - Shot 3. Air Blast Pressure at Ground Level versus Time. Full Time History

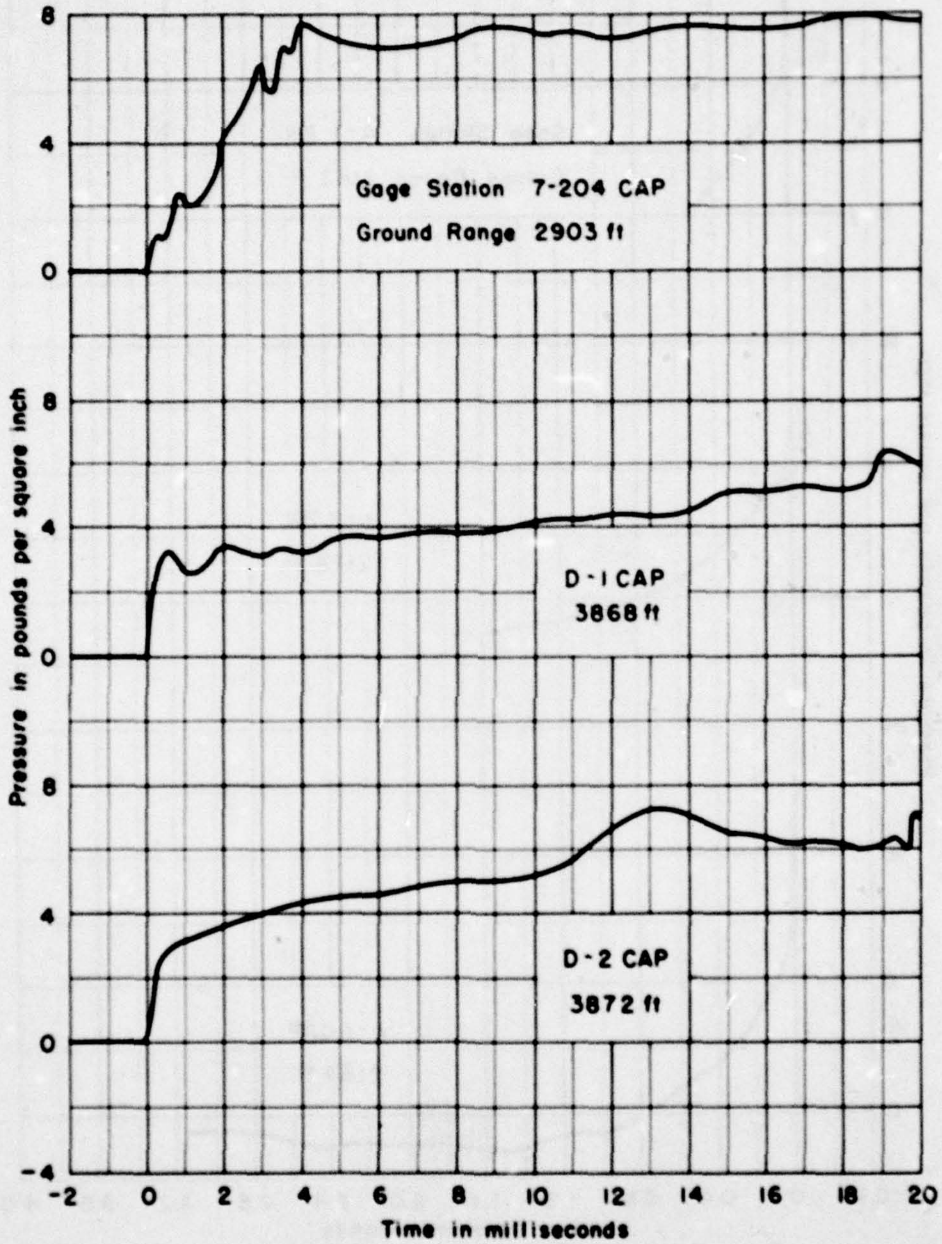

Figure 2.3a - Shot 3. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

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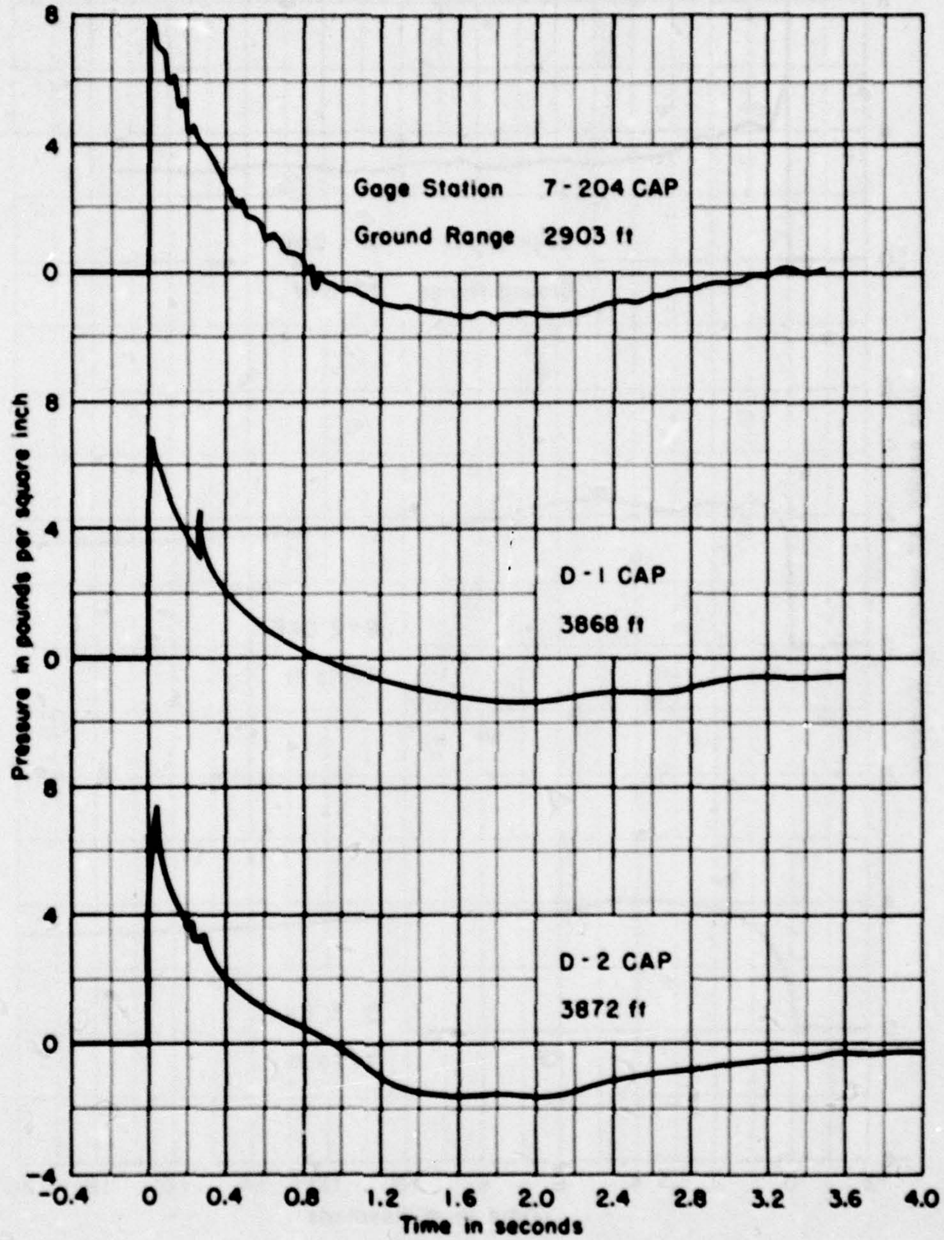

Figure 2.3b - Shot 3. Air Blast Pressure at Ground Level versus Time. Full Time History

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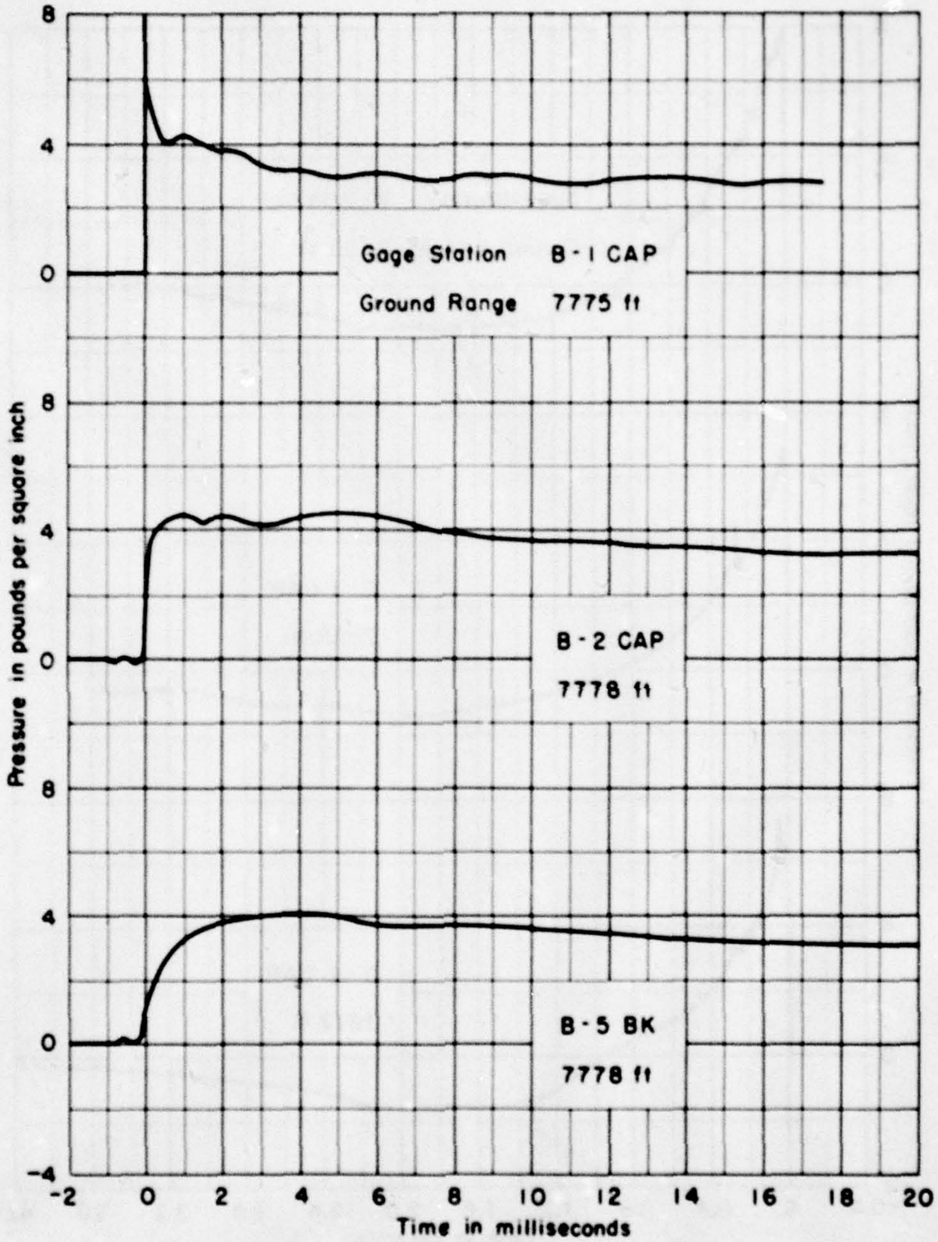

Figure 2.4a - Shot 3. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

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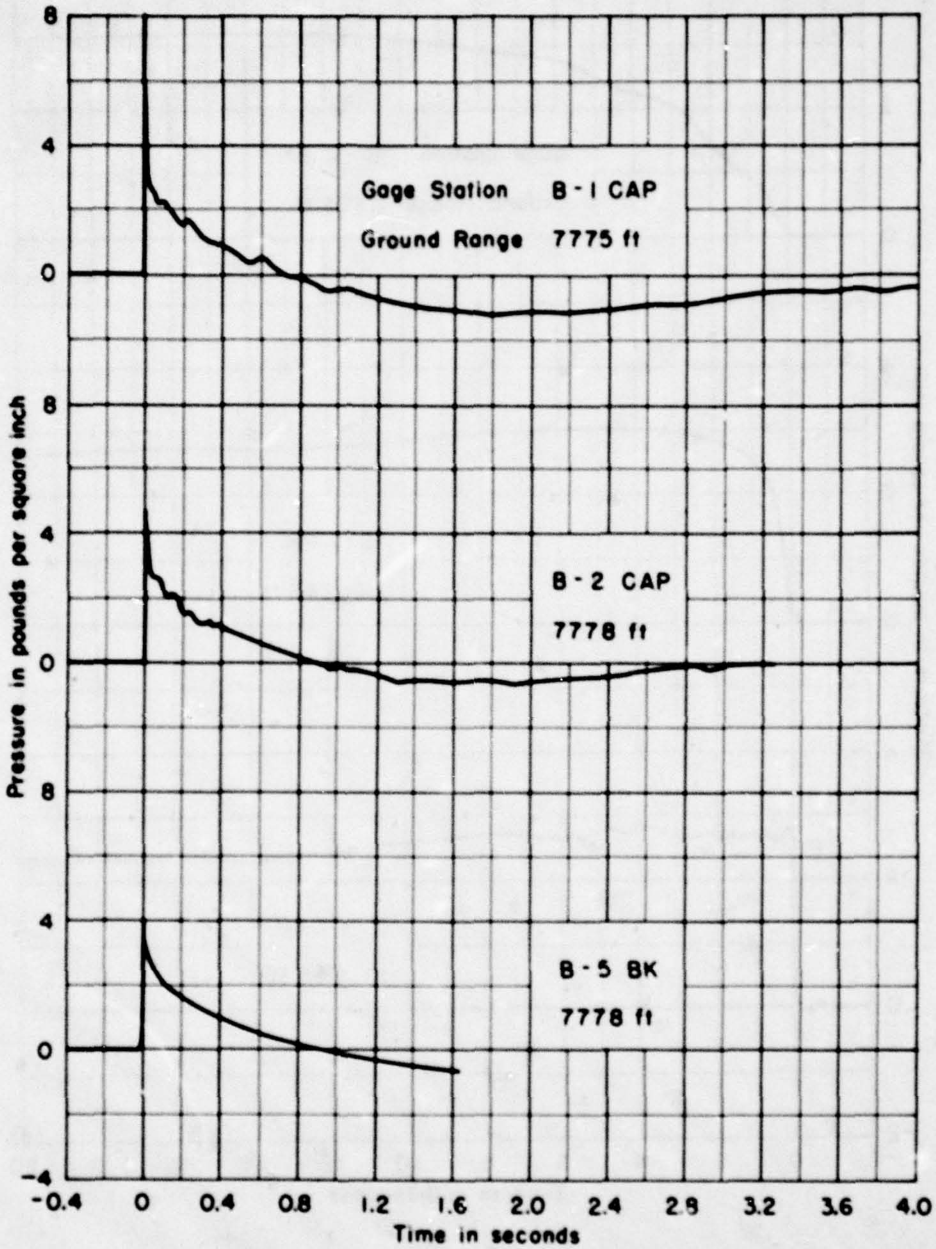

Figure 2.4b - Shot 3. Air Blast Pressure at Ground Level versus Time. Full Time History

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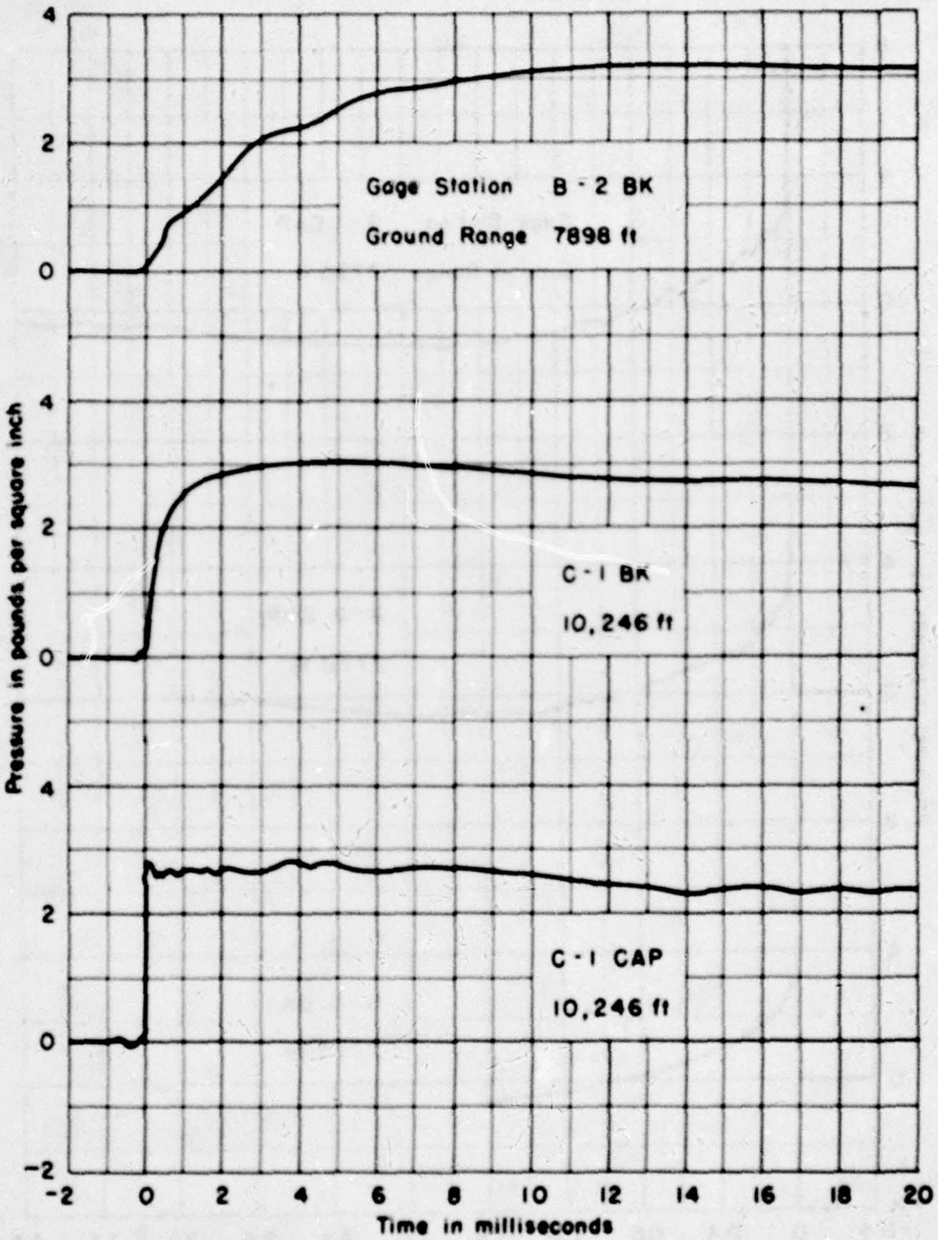

Figure 2.5a - Shot 3. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

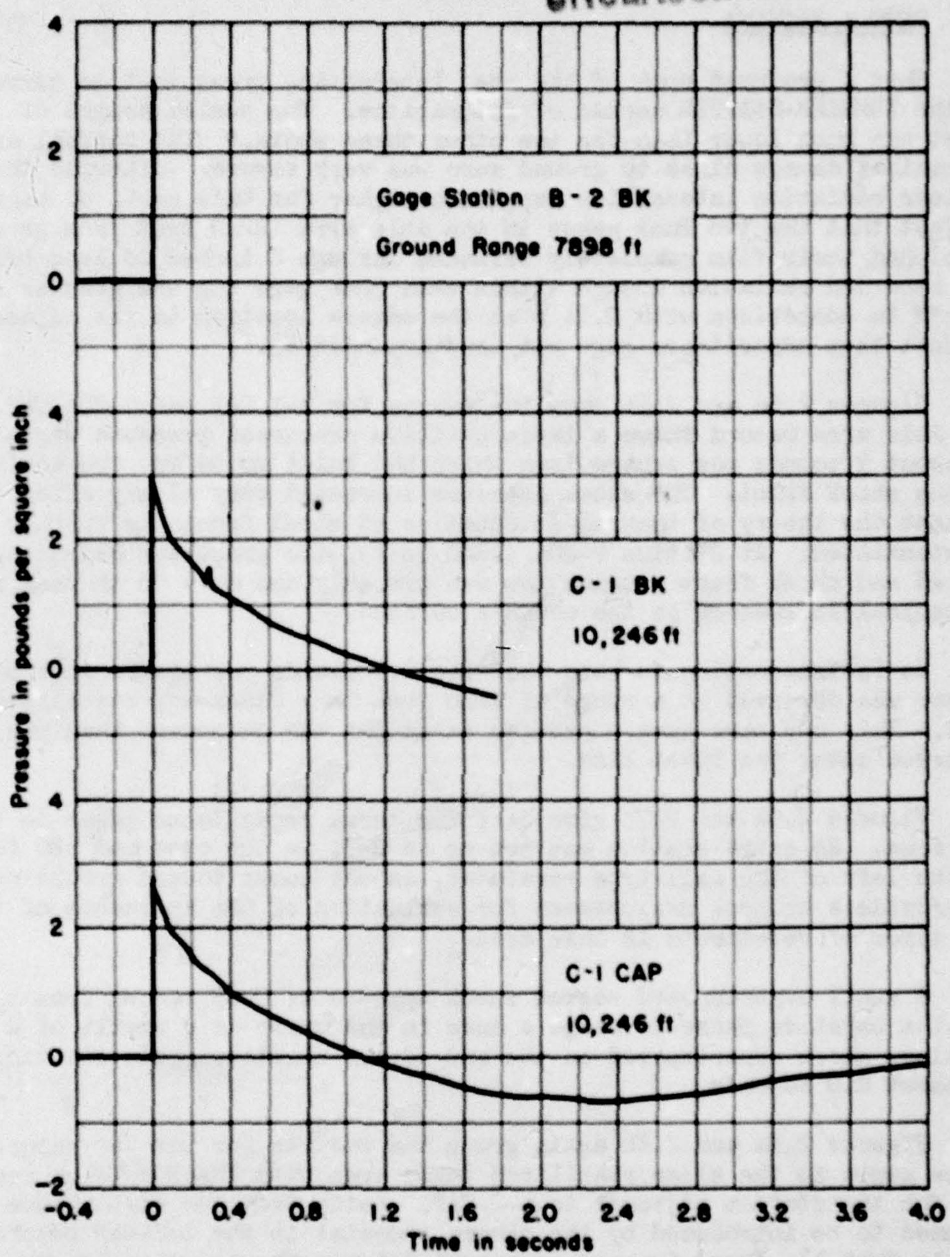

Figure 2.5b - Shot 3. Air Blast Pressure at Ground Level versus Time. Full Time History

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2.5 **SHOT 4 RESULTS**

Shot 4 produced some of the most interesting pressure-time curves of the TUMBLER-SNAPPER series of detonations. The scaled height of burst was much lower than for the other three shots.* The thermal and mechanical damage close to ground zero was very severe. Likewise the nuclear radiation intensities were much higher for this shot, so high in fact that the two Buck gages in the Able area (2240 feet from ground zero) had their film completely darkened through 8 inches of lead brick. The recorded radiation dosage within each Buck gage box was greater than 20 r** in comparison with 0.14 r at the camera location in the adjacent 10 foot deep capacitance-gage pit (see Appendix B).

Figures 2.6a and 2.6b show the curves for A-1-CAP and 7-204-CAP. The Able area record shows a large positive precursor pressure signal of about 3 pounds per square inch which had built up before the arrival of the shock front. The shock pressure increased very slowly after t_o so that the theory of thermal attenuation of shock fronts is further substantiated. At Station 7-204 (2840 feet), the precursor had disappeared and shock front attenuation was probably due only to thermal and mechanical influences on the earth's surface.

It is interesting to note that the 2.7 pounds per square inch precursor was observed at a range of 2240 feet in a black-top stabilized area. This may have been a greater range for the phenomena than was observed along the blast line.

Figures 2.7a and 2.7b give data for three capacitance gages in the Dog area. An extra station was set up as D-3, in the open and 380 feet to the left of the wall-type revetment, as one looks toward ground zero, to provide a control measurement for evaluation of the influence of the two types of revetments in this area.

A small superimposed second shock appears at 0.65 second from t_o, and the negative phase develops a knee in the curve as a result of a tertiary shock superimposed on the end of the negative phase starting at about 2.0 seconds.

Figures 2.8a and 2.8b again group the results for the two capacitance gages in the clear stabilized Baker area with the Buck-gage record for the station adjacent to B-2-CAP. Aside from the disturbance assumed to be introduced by the camera pedestal in the B-2-CAP record (as in Shot 3), there is good agreement between the two capacitance

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*Height of burst scaled to 1 kiloton at sea level—747, 995, 1012 and 363 feet respectively for Shots 1, 2, 3 and 4.

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TABLE 2.3

Ground Level Pressure Data - Shot 4

Gage Station	Ground Range feet	Slant Range feet	Peak Positive Pressure psi	Positive Phase Duration sec	Positive Impulse psi-sec	Maximum Negative Pressure psi	Negative Phase Duration sec	Negative Impulse psi-sec
A-1-CAP	2240	2470	12.5	0.88	5.86	3.8	1.21	2.70
7-204-CAP	2840	3030	8.7	0.80	2.54	2.12	2.00	2.44
D-1-CAP	3800	3940	7.38	0.75	2.15	1.67	2.7	1.95
D-2-CAP	3810	3950	5.96	0.81	1.72	1.67	2.9	2.14
D-3-CAP	3820	3960	6.3	0.87	2.10	1.70	3.1	2.12
B-1-CAP	7710	7780	2.1	1.04	0.86	0.74	2.2	0.83
B-2-CAP	7720	7790	2.6	1.00	0.84	0.75	2.17	0.70
B-5-BK	7720	7790	2.57	1.03	1.12	0.50	(a)	(a)
B-3-BK	7730	7800	2.28	1.05	1.00	0.71	(a)	(a)
B-1-BK	7910	7980	1.91	0.73	0.66	0.76	1.42	0.63
C-1-BK	10190	10240	1.72	(a)	(a)	(a)	(a)	(a)
C-1-CAP	10190	10240	1.75	1.00	0.67	0.60	2.25	0.74

(a) End of film.

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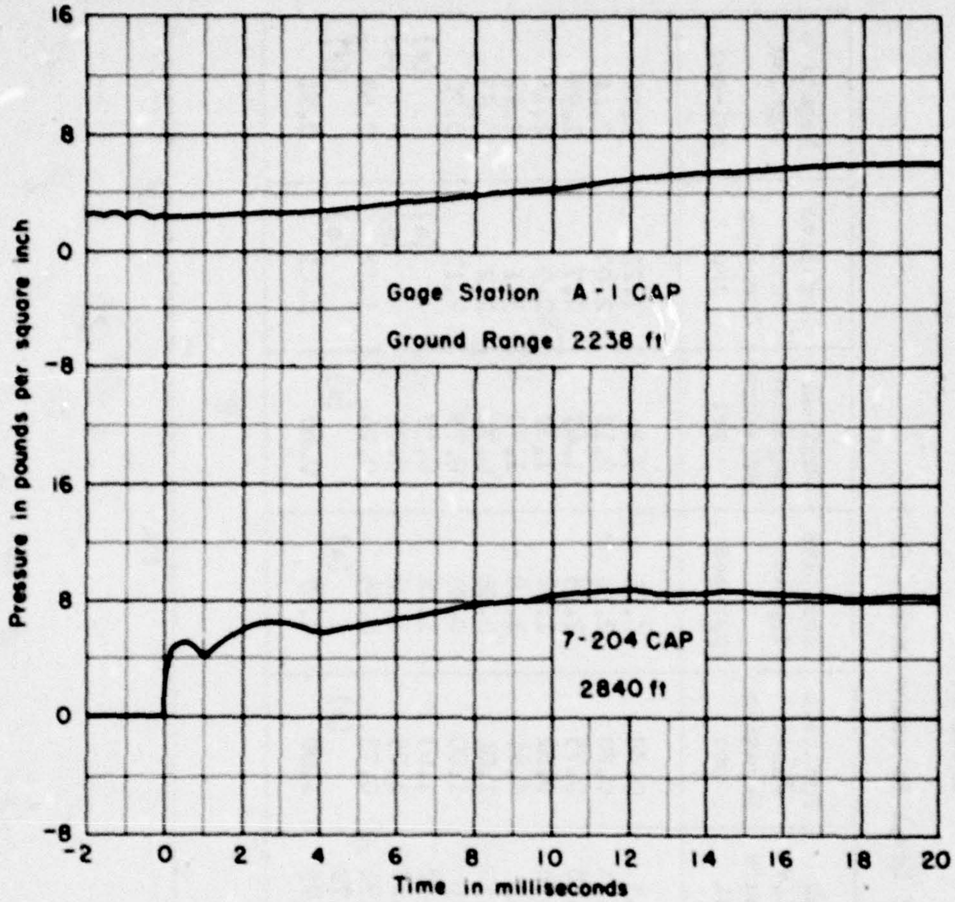

Figure 2.6a - Shot 4. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

gages as evidenced by positive impulse values of 0.86 and 0.84 pounds per square inch per second. The Buck gage also is in reasonably good agreement with a positive impulse value of 1.12 pounds per square inch per second. The Buck-gage record, however, points up the possibility of reaching false conclusions as to the true shape of a wavefront if the frequency response of the recording system is not fully considered. The Buck-gage record shows that the shock front took 5 msec to reach a peak; from this it might be erroneously concluded that thermal attenuation effects were present out to the 7700 foot distance. Positive phase durations agree very closely but the occurrence of the superimposed secondary shock in the middle of the positive phase was at slightly different times for the three gages. Negative phases in the capacitance-gage records exhibit the same characteristic knee as at the Dog stations.

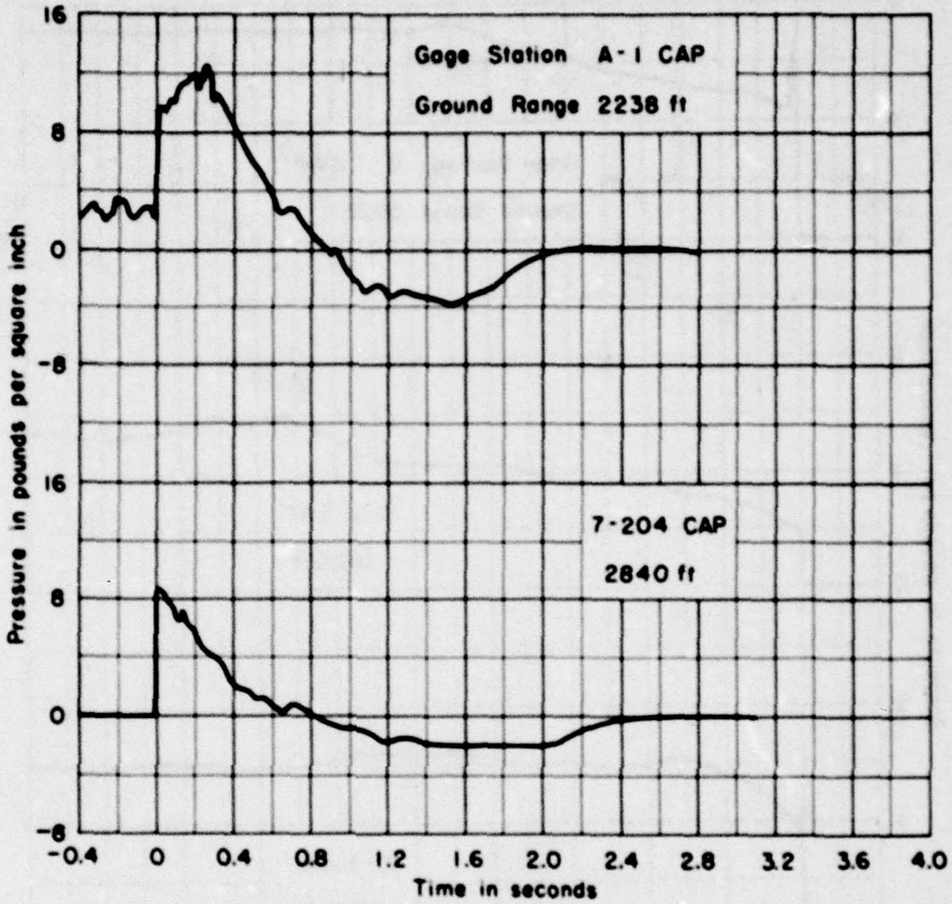

Figure 2.6b - Shot 4. Air Blast Pressure at Ground Level versus Time. Full Time History

Unfortunately the Buck-gage record did not include all of the negative phase.

The remaining records of the report are presented as Figures 2.9a and 2.9b. Two Buck gage records were obtained in the vicinity of the G-type revetment. Gage B-1-BK was behind the revetment at the foot of the back slope and B-3-BK was at the foot of the front slope but in the clear toward ground zero. The B-3-BK gage record can be compared with the curves of Figure 2.8 since all were located in line at about the same range. Such comparison reinforces the agreement shown in Figure 2.8.

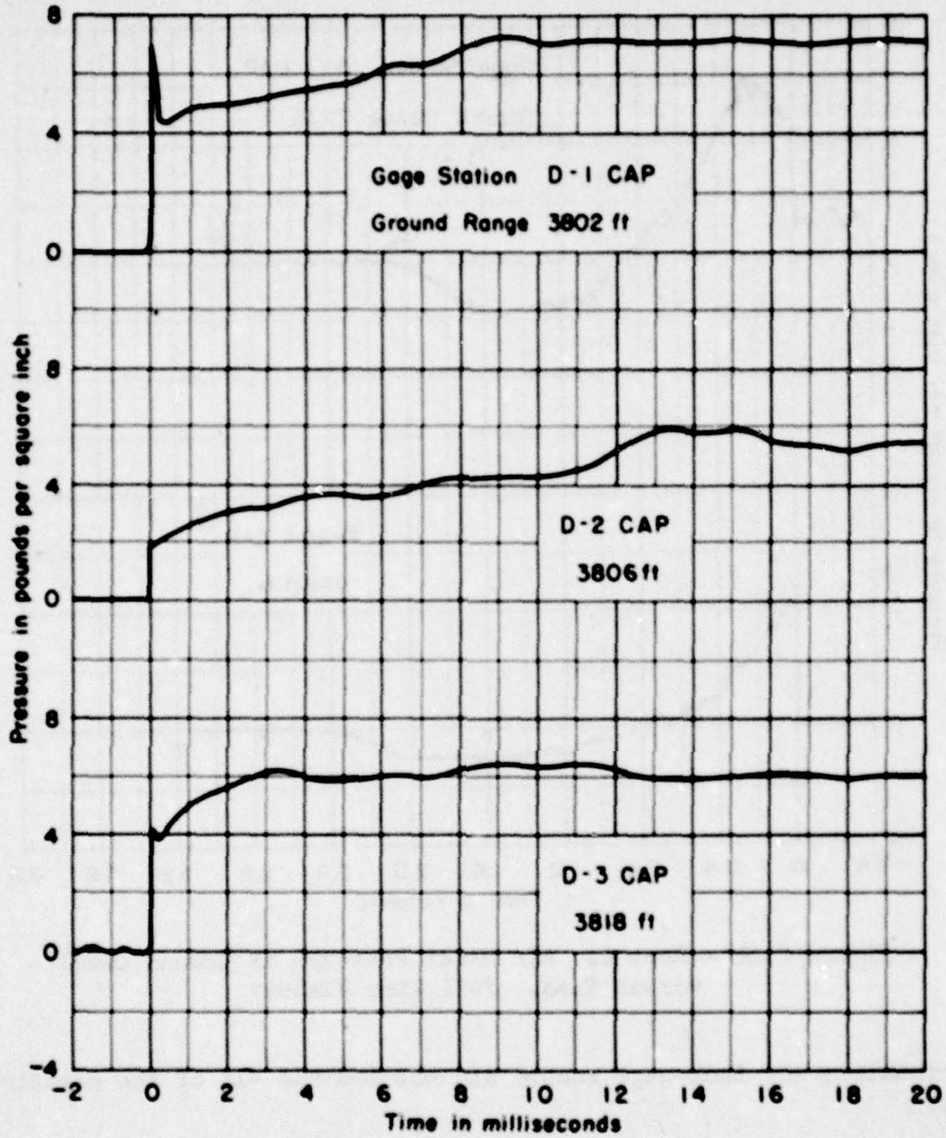

Figure 2.7a - Shot 4. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

[redacted]

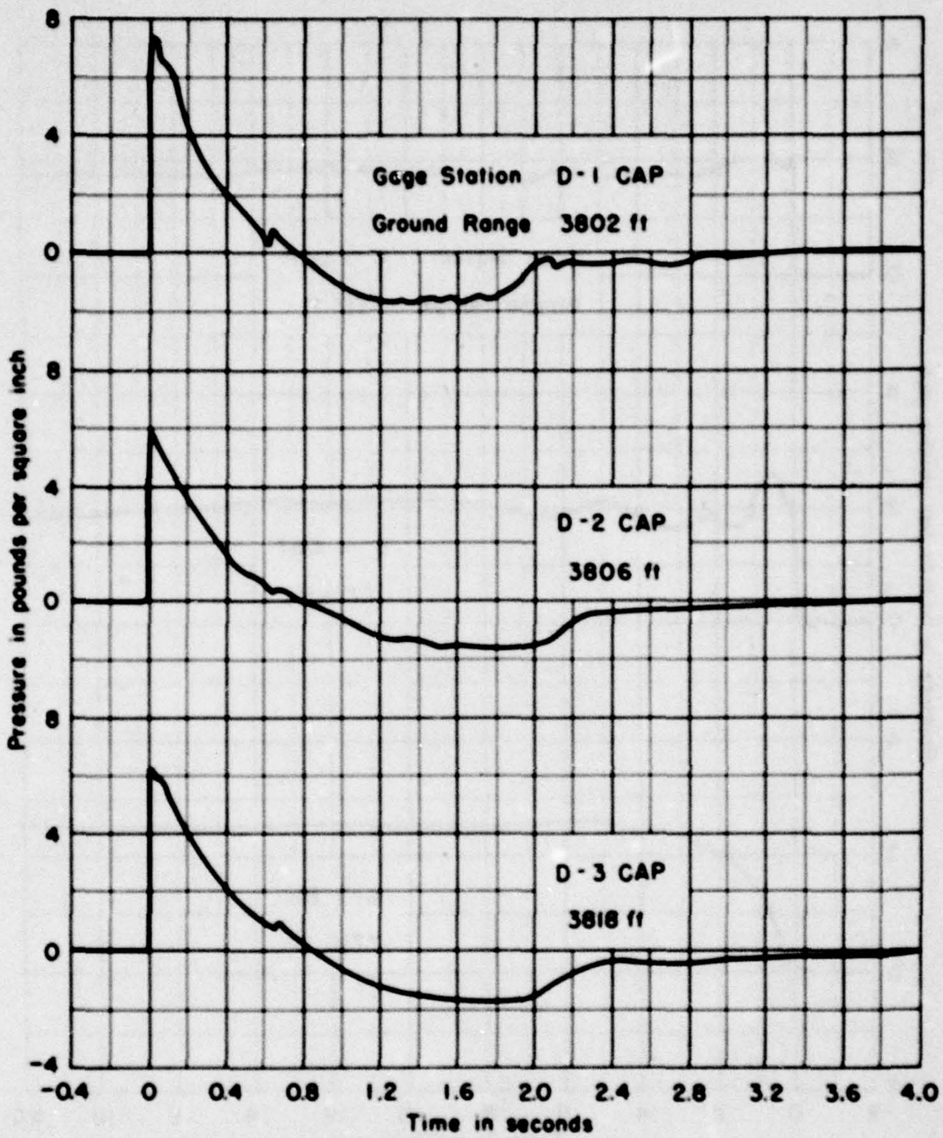

Figure 2.7b - Shot 4. Air Blast Pressure at Ground Level versus Time. Full Time History

[redacted]

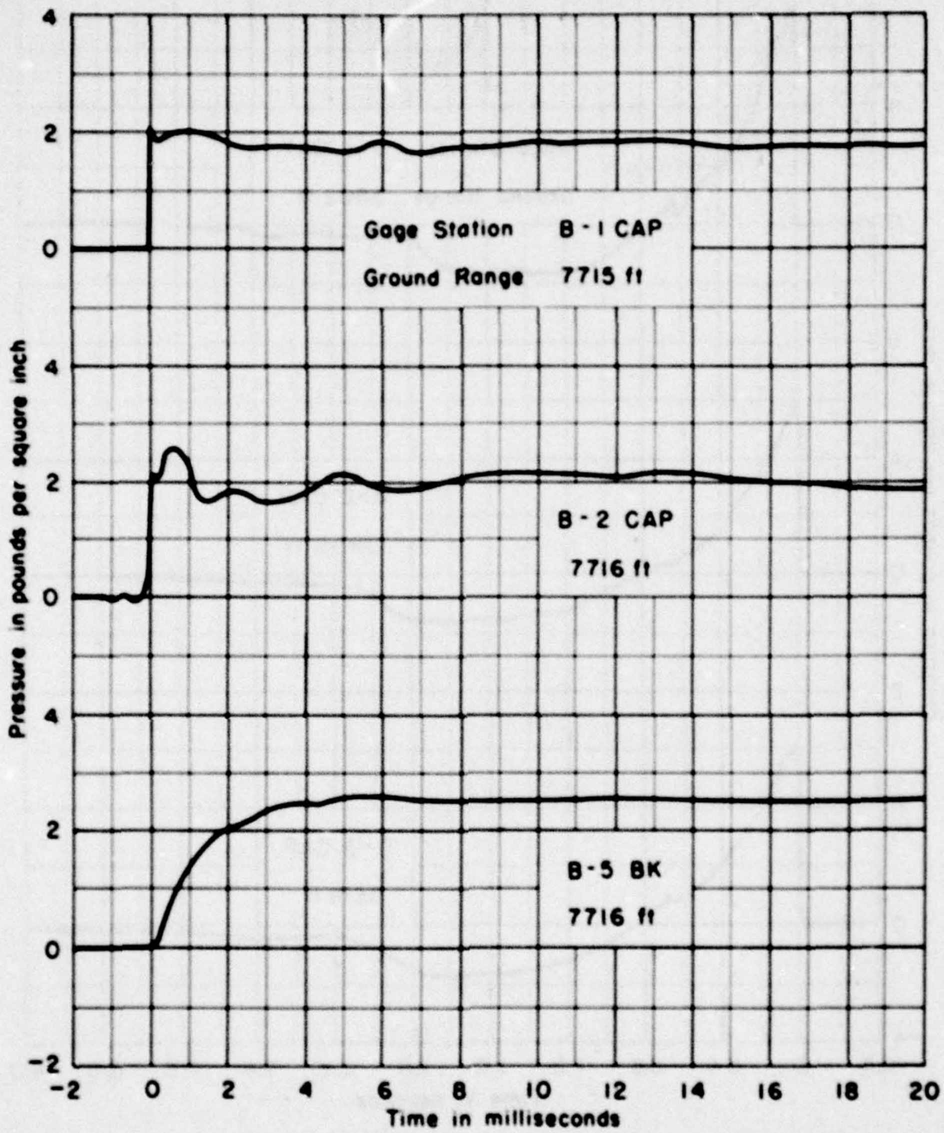

Figure 2.8a - Shot 4. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

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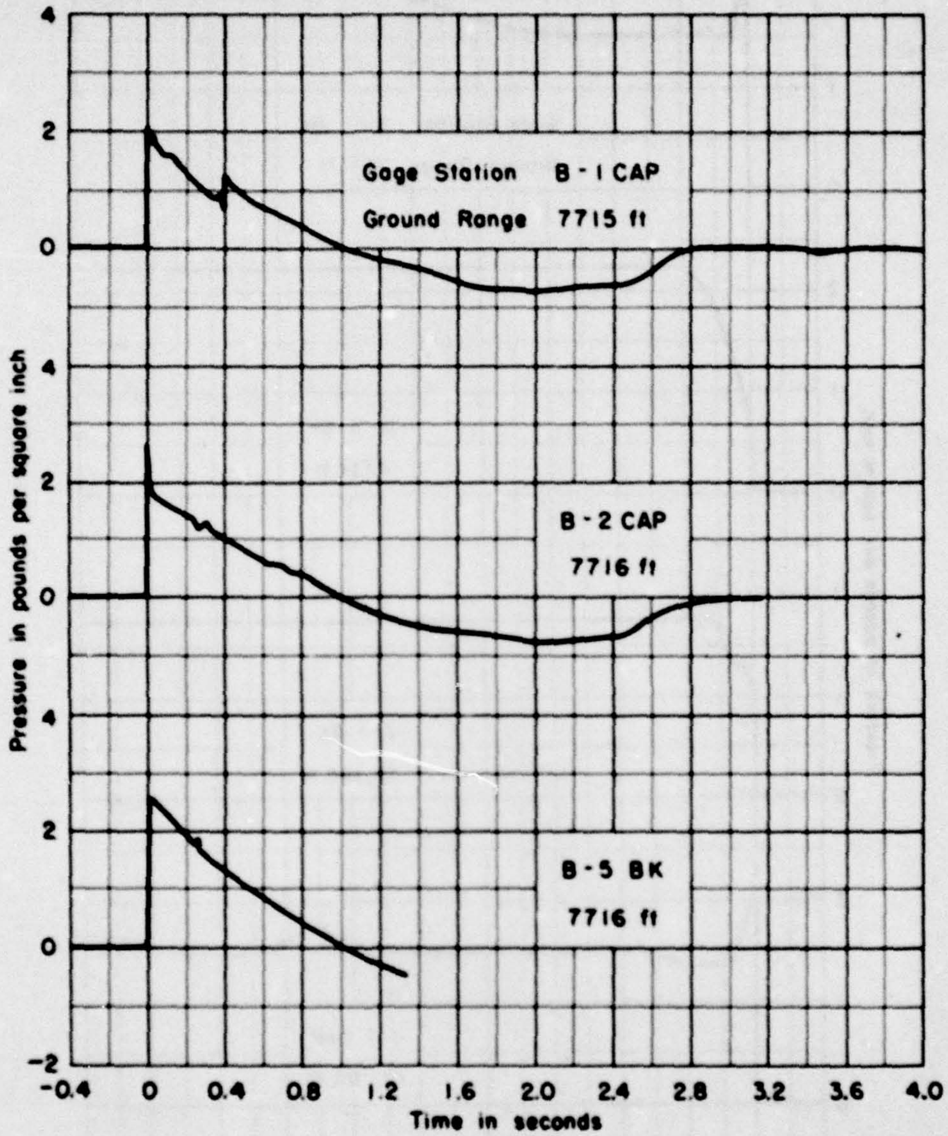

Figure 2.8b - Shot 4. Air Blast Pressure at Ground Level versus Time. Full Time History

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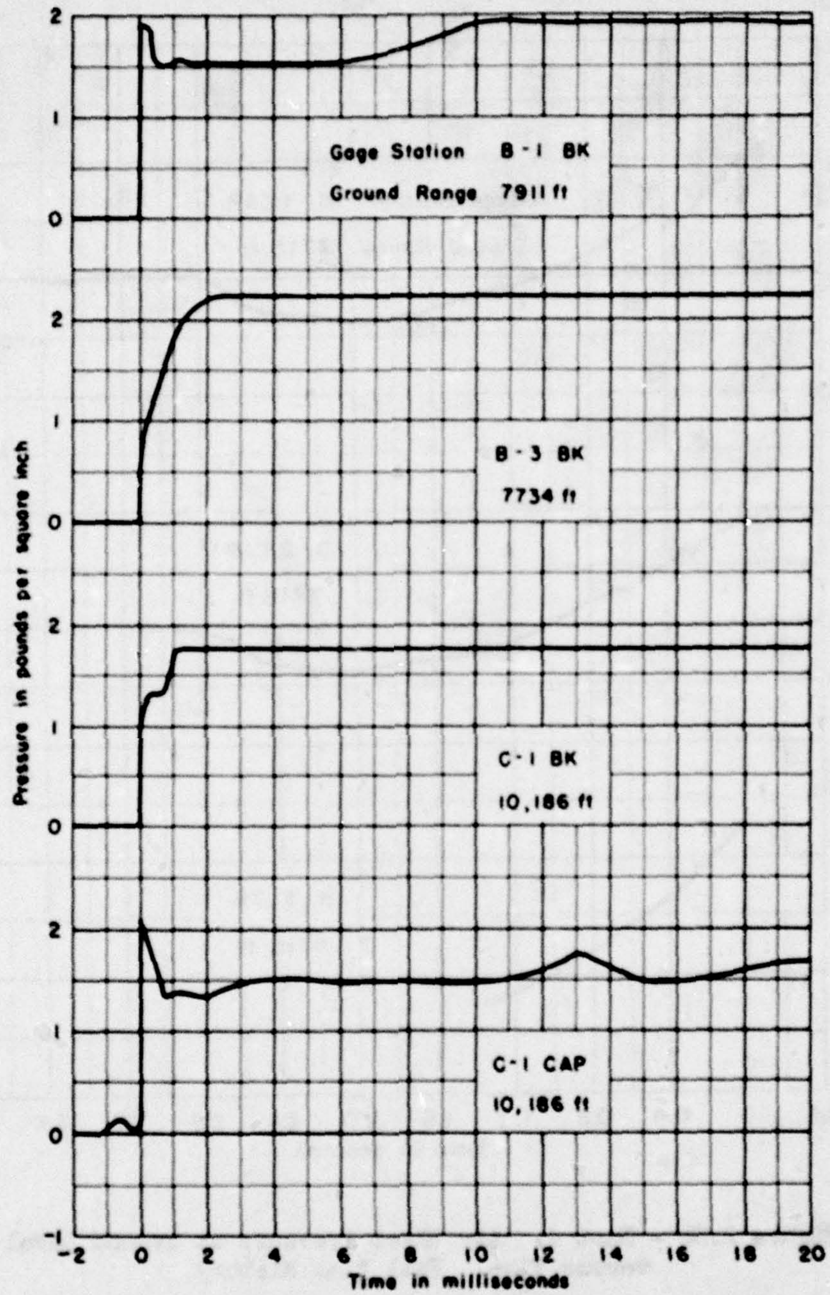

Figure 2.9a - Shot 4. Air Blast Pressure at Ground Level versus Time. Shock Front Shape and Rise Time

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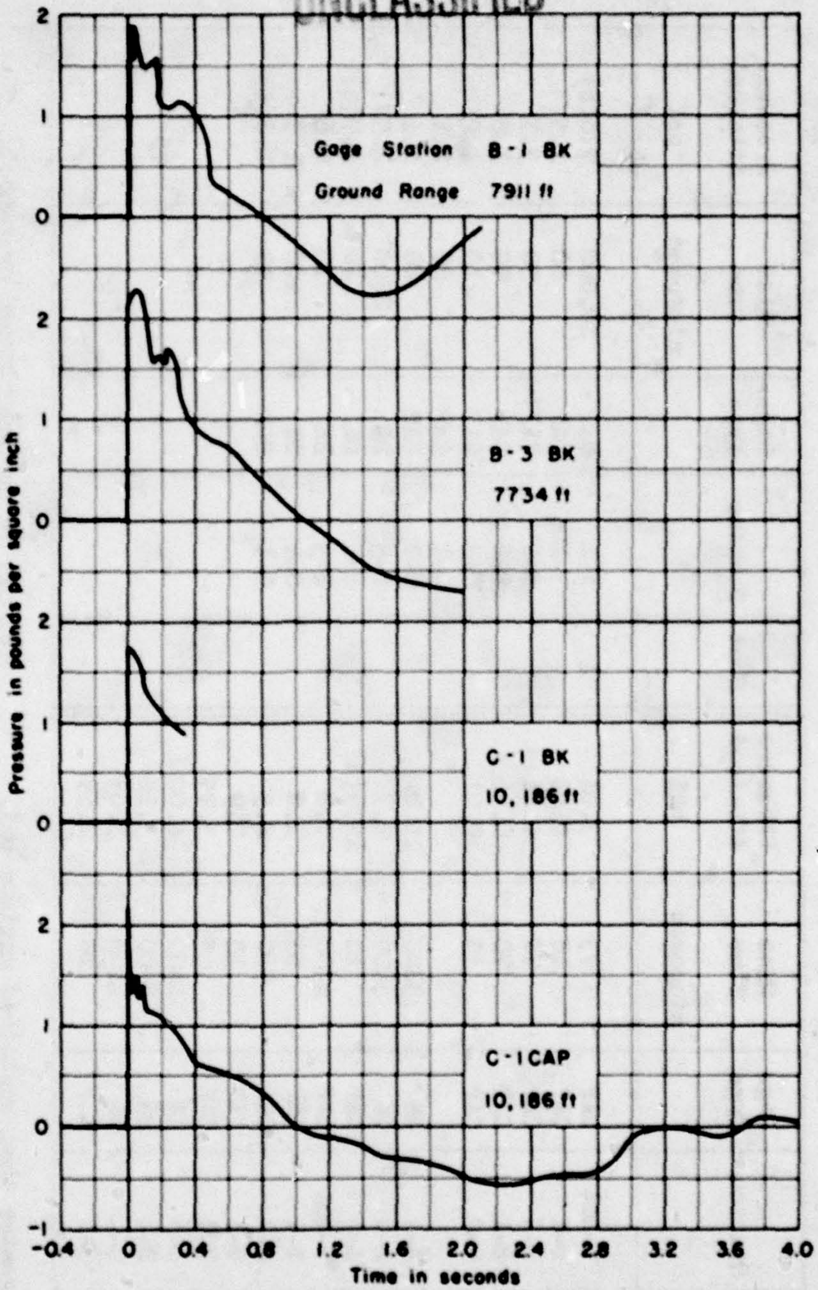

Figure 2.9b - Shot 4. Air Blast Pressure at Ground Level versus Time. Full Time History

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TABLE 2.4

Shock Front Rise Time, Shots 2, 3, and 4

Shot	Station	Gage Type	Rise Time microsec	Pressure Attained psi	Shot	Station	Gage Type	Rise Time microsec	Pressure Attained psi
2	7-204	CAP	73	3.61	4	A-1	CAP	20,000	7.0(b)
	D-1	CAP	10	0.83		7-204	CAP	60	2.5
	D-2	CAP	78	0.41		D-1	CAP	30	3.7
	B-1	CAP	70	0.96		D-2	CAP	70	1.8
	B-2	CAP	10	0.91		D-3	CAP	10	4.2
						B-1	CAP	60	2.1
3	A-1	BK	3200	15.0		B-2	CAP	80	2.1
	A-2	BK	3100	8.7		B-5	BK	2000	2.57
	A-1	CAP	10	19.9(a)		B-1	BK	10	1.9(c)
	7-204	CAP	4000	7.8		B-3	BK	10	0.6
	D-1	CAP	50	1.8		C-1	BK	200	1.3
	D-2	CAP	360	2.5		C-1	CAP	10	2.2(d)
	B-1	CAP	10	7.9					
	B-2	CAP	65	3.95					
	B-5	BK	1600	4.00					
	B-2	BK	2700	3.18					
	C-1	BK	1100	3.03					
	C-1	CAP	10	2.59					

(a) Greater than sustained maximum psi.
(b) Above the 2.7 psi precursor.
(c) May be an underdamped overshoot.
(d) Porex correction applied.

The B-1-BK record shows evidence that the combined effect of the front and back walls of the G-type revetment result in some reduction to both peak positive pressure and positive impulse, about 20 per cent each. Of course the inside of the revetment is the assumed protective area for aircraft but because of the failure of B-2-BK on this shot the only information on the protection offered by the revetment (other than observed damage to aircraft) is the approximately 35 per cent reduction in average peak positive pressure experienced within the revetment for Shot 3.

The last two records are for the Charlie location and again good correlation is shown between the two types of gages. Shot 4 data are summarized in Table 2.3.

Table 2.4 summarizes the rise times for all gages on Shots 2, 3, and 4 to the <u>first</u> <u>distinct</u> <u>positive</u> <u>peak</u>. Peak values reported in this table may or may not be the maximum pressures attained, depending upon whether subsequent maxima exceed the first peak in amplitude.

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CHAPTER 3

CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

The peak ground-level air-blast pressures recorded by the David Taylor Model Basin at Station 7-204 on the main blast line for Shots 2, 3, and 4 agree within 3 per cent with the average of all other pressure measurements at that location. With good agreement at a common location it would seem that direct pressure comparisons could be made between records obtained by Project 1.13 in aircraft parking areas away from the blast line with those obtained by other projects at comparable distances along the blast line. It appears that most variations that may be noted from such comparisons can be attributed to local conditions of terrain, surface composition, and proximity of above ground structures or objects. Such influences, however, are very pronounced at certain locations.

Capabilities of the Taylor Model Basin capacitance gage system are such that true representations of steep-fronted waveforms are obtained down to a limitation of 10 microseconds rise time. Good agreements were observed with low frequency-response pressure measuring systems at Station 7-204 because the rise times to the maximum positive pressure at that station were slow--3.0 msec, 4.0 msec, and 12.0 msec respectively for Shots 2, 3, and 4. Where wavefronts are steep, peak pressure, as determined by graphical extrapolation of records from low frequency gage systems, generally give values that are lower than those recorded by the capacitance gage system.

As an aid in the correlation of structural damage to aircraft, the peak positive pressures and positive impulses have been presented with the data of this report as averages for five different ranges and as direct comparisons between the results of Shots 3 and 4; see Table 3.1. It will be noted that for a range of 2100 feet, the peak pressures for Shots 3 and 4 were about equal but the impulse value for Shot 3 was only one-half that for Shot 4. At an intermediate range of 7800 feet, the impulse values were equal but the peak pressure for Shot 4 was one-half that for Shot 3--just the opposite of the relationship for the near-in range. In a transitional range of 3000-3800 feet, pressures and impulses were almost identical respectively for the two shots. At the more extreme range of 10,200 feet, the pressure and impulse values are consistent with one another, viz., lower pressures for Shot 4 were associated with corresponding lower impulse values as compared to Shot 3 values.

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TABLE 3.1

Positive Pressures and Impulses for Shots 3 and 4

Range feet	Shot 3		Shot 4	
	Pressure psi	Impulse psi-sec	Pressure psi	Impulse psi-sec
2100	12.0(a)	2.6(a)	12.5	5.9
3000(f)	7.9	2.7	8.7	2.5
3800	7.1(b)	2.0(b)	6.6(c)	2.0(c)
7800	4.9(d)	0.9(d)	2.4(d)	0.9(d)
10,200	2.9(e)	1.1(e)	1.7(e)	0.7(e)

(a) Average of A-1-BK, A-2-BK and A-1-CAP
(b) Average of D-1-CAP and D-2-CAP
(c) Average of D-1-CAP, D-2-CAP and D-3-CAP
(d) Average of B-1-CAP, B-2-CAP and B-5-BK
(e) Average of C-1-BK and C-1-CAP
(f) Single gage reading at 7-204-CAP

David Taylor Model Basin records for this series of tests are believed to have an over-all accuracy of 5 per cent with possibly slightly less accuracy for certain negative phase phenomena. The capacitance gage recording system proved very satisfactory for these tests. Only one gage failed to operate properly and this was due to the complete inundation of an instrument shelter before a shot. The shelter could not be dried out sufficiently before the equipment was installed and the moisture shorted out a high voltage circuit.

The application of the Buck interferometer gages to these tests was not, on the other hand, nearly as satisfactory. The gage is difficult to adjust, unpredictable in performance from one operation to the next and difficult to shield from nuclear radiations. Out of 23 Buck gage installations made for Shots 2, 3, and 4 by Project 1.13 only eight usable pressure records were obtained. Two records were lost because the 8 inches of lead shielding did not provide sufficient protection for the film from nuclear radiations on Shot 4.

3.2 RECOMMENDATIONS

The recommendations offered by Project 1.13 relate mainly to improvements in instrumentation for air-blast pressure measurements on future atomic weapons tests. A major purpose of any field test program

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is to produce data--reliable data. The instrumentation should meet standards of accuracy and resolution consistent with the end use of the data. The more reliable the instrumentation and the simpler the installation the greater the chance that all data desired will be obtained and the cost of securing these data in both time and money will be minimized.

It appears that there is considerable advantage to be gained by the use of independent self-contained gage stations with all of the equipment located in a small hole such as could be bored in the earth with a power auger. The recorder for each station should be reasonably low in cost but even this cost could be offset by the elimination of long cable trenches, the multiple cables in these trenches, and the large underground shelters required for central recording stations. Certain operational difficulties experienced with long cables in sensitive gaging and recording systems would also be eliminated.

Should it be desired on any future tests to study the exact waveforms of shock fronts or precursors it is suggested that the use of the capacitance gage system with its proven high frequency response be considered. This measurement system is self contained, rugged, and reliable, and can be readily adjusted for full scale recording on any one of several pressure ranges with automatic electrical calibration inherent for each range.

Since preparation time for TUMBLER-SNAPPER was so limited, certain desirable refinements in the measurement apparatus, that could not be incorporated at that time, are suggested here:

1. It seems desirable to use a stretched steel diaphragm as the pressure sensing element in the gage head. The air space behind the diaphragm, including the capacitance gap, should be evacuated and sealed. This will minimize long term variations in the pressure reference datum that occur as a result of slow changes in the gage temperature and the resulting influence on the air pocket. In the existing gage system, as used on TUMBLER-SNAPPER, these slow variations were compensated for by an automatic rebalancing circuit. It is believed that adequate protection from rapid thermal flux changes is provided by the thermal and dust filter used over the diaphragms.

2. A redesign of the physical arrangement of the apparatus is indicated so the assembly could be fitted in a waterproof cylindrical housing that might be lowered into a 24 inch standpipe in the ground. Then a baffle plate could be placed atop the pipe for ground level measurements or a smaller pipe could be extended to support a baffle for above ground measurements.

3. It would be desirable for the recorder to run at least 7 seconds so that the pre-shock zero reference datum could be rechecked at

the end of the film after all air-blast effects had terminated.

The experience of the Project 1.13 group with the Buck interferometer gages leads to the conclusion that these gages are not well suited to tests of this nature. Although some of the existing deficiencies could be corrected by redesign, it is felt that efforts could more profitably be devoted to development and improvement of other pressure recording systems for future atomic weapons tests.

APPENDIX A

THERMAL SHIELD REMOVER

A.1 GENERAL

The best information available to Project 1.13 during the preparatory stages for the TUMBLER-SNAPPER operation indicated that the expected thermal flux intensity for ground ranges corresponding to our gage stations closest to G.Z. might be high enough to fuse the sintered brass Porex filters and prevent the pressure from reaching the sensitive diaphragms.

For this reason an arrangement was worked out whereby a thermal shield positioned directly over the gage would be removed shortly after bomb detonation and before the arrival of the pressure wave.

The effectiveness of the thermal shield remover in carrying out its mission was demonstrated in the Able area on Shot 4. The whitewashed gage baffle plate was scorched except where the shield cylinder protected the gage area. The pressure wave was recorded satisfactorily indicating that the shield was removed at the proper time.

The shield consisted of a 5 inch diameter sheet metal cylinder 8 inches long with one end open and a 2 foot square of plywood as a cap on the top. The open end of the cylinder was placed on the baffle plate directly over the gage. An attached gasket ensured a close fit to the baffle. The shield was held in place with light strings anchored to small pegs in the ground.

The device that removed the shield consisted of an 8 foot long 1 1/4 inch pipe pivoted at one end where it attached to a capstan-like device mounted on an axle driven into the ground. The capstan or pivot point was so located that the arc-of-swing of the free end of the arm intersected the shield over the gage. A fork arrangement on the end of the arm caught the shield cylinder, picked it up and threw the shield away from the gage area.

Capstan power was provided by a heavy garage-door type coil spring housed in an iron pipe and secured at one end. The pipe was lined up on the ground so that a steel cable fastened to the free end of the spring could be wound around the capstan drum. The device was wound up by rotating the arm against the restraint offered by the spring. With a desired initial degree of tension in the spring, the rotational time or delay between the release of the arm and the removal of the shield was controlled by choice of the anchor point.

The anchor point was so chosen that about 0.7 second delay was obtained after detonation time. The "loaded" arm was restrained at the anchor point by a heavy cord attached to a cellulose tape which was looped around an explosive squib. The squib was secured at the anchor point. On signal from a "blue box" circuit the squib exploded to break the tape and release the arm. When the arm had moved part of the way around, it was caused to simulate a break in a blast foil and start the camera for A-1-CAP.

A movie was made of a trial operation of this device on 18 April 1952 (Film No. P-16-100-6, Documentary Photographic Unit, Los Alamos Scientific Laboratory).

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APPENDIX B

GAMMA RADIATION DOSAGES IN INSTRUMENT SHELTERS

B.1 GENERAL

To provide information on the effectiveness of the shielding employed to protect camera film from nuclear radiation, film badges were placed in the various Project 1.13 instrument shelters for Shots 2, 3, and 4. The film badges were furnished and processed by Program 4.

Table B.1 lists the total dosages recorded in the various shelters. The capacitance gage shelters were underground structures with shielding provided by the earth. Buck gages in the Able area were shielded with lead brick. At other locations the Buck gages were shielded only by a steel box recessed flush with the ground surface.

On Shot 4 the 8 inches of lead for the Buck gages did not provide sufficient shielding and the records for the Able area were lost. The film badges inside the two Buck gage boxes read greater than 20 r and the camera film was completely opaque after development. The slant distance through the lead shielding was about 19 inches. It is of interest that the aluminum film spools measured 20 mr 30 hours after shot time.

The adjacent capacitance gage instrument shelter received only 0.14 r at the camera location in the bottom of the 10 foot deep shelter. Even at a 6 foot level the dosage was only 1.32 r for Shot 4.

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TABLE B.1

Instrument Shelter Radiation Dosages

Gage Station	Location of Film Badge	Nominal Ground Range feet	Dosages, Roentgens Shot 2	Shot 3	Shot 4
A-1-CAP	Camera level at bottom of shelter	2200	(a)	0.05	0.14
	Sandbag shelf level		0	0.74	1.32
A-1-BK	In gage box under 6 inches of lead		2.05	4.5	
	In gage box under 8 inches of lead				> 20.0
A-2-BK	In gage box under 6 inches of lead		2.2	5.0	
	In gage box under 8 inches of lead				> 20.0
7-204-CAP	Camera location at bottom of shelter	2900	0	0.09	0.245
	Sandbag shelf level		(a)	0.48	(a)
D-1-CAP	Camera level at bottom of shelter	3900	0.07	0.24	2.08
D-2-CAP	Camera level at bottom of shelter		0.07	0.50	2.20
D-3-CAP	Camera level at bottom of shelter		(b)	(b)	0.045
B-1-BK	In gage box - no lead shielding	7800	0	0.42	(a)
B-2-BK	In gage box - no lead shielding		0	(a)	0.040
B-3-BK	In gage box - no lead shielding		(a)	0.62	(a)
B-4-BK	In gage box - no lead shielding		(a)	0.45	0.18
B-5-BK	In gage box - no lead shielding		0.02	0.60	0.245
B-1-CAP	Camera level at bottom of shelter		0	0	0
B-2-CAP	Camera level at bottom of shelter		0	0	0
C-1-BK	In gage box - no lead shielding	10,200	(b)	(a)	(a)
C-1-CAP	In gage box - no lead shielding		(b)	0	0

(a) No badge used
(b) Station not used

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